IMPACT

of science on society

Vol. IX (1959)
No. 4 [A] Price: $0.50; 2/6 (stg); 125 FF (1,25 NF)

PERIODICAL
READING ROOM

IN THIS ISSUE:

How Life on Earth began by A. I. OPARIN

The Place of Laboratory Animals in the Scientific Life of a Country by W. LANE-PETTER

The Place of Operational Research in the Development of Modern Society by J. LESOURNE

Current Problems and Recent News

IMPACT *of Science on Society*
quarterly

Annual subscription:
[A]
$1.75; 9/6 (stg.); 450 FF (4,50 NF)

Any of the National Distributors listed at the end of this number will accept subscriptions; rates in currencies other than the above will be supplied on application to the National Distributor in the country concerned.
When notifying change of address please enclose last wrapper or envelope.

The articles appearing in *Impact* express the views of their authors, and not necessarily those of Unesco.

© Unesco 1959
Printed in France
NS.59/I.33/A

UNITED NATIONS EDUCATIONAL, SCIENTIFIC
AND CULTURAL ORGANIZATION
Place de Fontenoy, Paris-7e (France)

Contents

Impact, Vol. IX (1959), No. 4

HOW LIFE ON EARTH BEGAN
by A. I. OPARIN 169

Life is represented on earth by a multitude of different organisms constituting separate living beings. Our direct observation and experience persuade us that the only way in which any living creature comes into existence at the present time is by being born of creatures of a similar kind (principle of biogenesis). This is true alike of highly organized plants and animals and of the most primitive organisms. But during the initial periods of the existence of our planet, under different conditions the transformation of carbon compounds into simple organic compounds may well have taken place by biogenetic processes.

THE PLACE OF LABORATORY ANIMALS IN THE SCIENTIFIC LIFE OF A COUNTRY
by W. LANE-PETTER 178

The reduction of ill-health in underdeveloped countries and the progress of medicine in advanced ones depend on forwarding medical research in every practicable way. Medical research in its turn relies largely on its basic material, the living animal. The provision of good laboratory animals for this purpose is therefore a pressing need for which adequate financial resources must be made available if medical and scientific services are to be given the opportunity of contributing to human health and welfare.

THE PLACE OF OPERATIONAL RESEARCH IN THE DEVELOPMENT OF MODERN SOCIETY
by J. LESOURNE 197

For several years now the branch of study known as Operational Research has made rapid strides. But—so the author of this article maintains—the age of operational research did not dawn suddenly; it developed slowly over several decades. Furthermore, the phenomenon of operational research is closely linked to a great number of other contemporary events. Mr. Lesourne outlines the influence that operational research can have on future social development; in particular he discusses its importance for the technical processes of production, for executive structures, for administrative structures, and for scientific thought itself.

CURRENT PROBLEMS AND RECENT NEWS

Science in Modern India
by Dr. A. Ranganathan 210

British influence on India resulted in a scientific renaissance which was inspired by the heritage of modern science. This was because India had not inherited a scientific tradition, despite some brilliant contributions to science by ancient India. Scientific research in modern India has been channelled through the learned societies, the scientific services and the universities. Notwithstanding the successful transmission of science in India up to the present, scientific progress is apt to be retarded by (a) the tendency to reject the universal spirit of modern Western civilization rooted in intellectual freedom, and merely to take over its technology, and (b) the anti-scientific forces of traditionalism.

Problems of Waste Disposal in the Wide-scale Use of Radio-isotopes
by W. G. Marley 231

It is now generally recognized that the exposure of living tissue to ionizing radiations can only be deleterious, and the extension of the use of radio-isotopes therefore raises the problem of minimizing the human exposures which must necessarily result. In the light of this the author discusses the following points: (a) the natural background of radio-activity; (b) the permissible levels of exposure to ionizing radiation; (c) the sources of radio-active wastes in the application of isotopes; (d) procedures for the control of radio-active wastes. He shows that with careful planning and proper quantitative supervision of the disposal procedure the widespread use of radio-active nuclides in scientific research, in medicine and in all branches of industrial technology can be very greatly expanded without risk to public health.

CONTENTS OF PRECEDING ISSUES

Vol. IX, no. 1, 1958
Industrial Diagnosis, by K. PENNYCUICK.
Water and Economic Development, by ALFRED LOEHNBERG.
Technological Humanism, by Sir ERIC ASHBY.

Vol. IX, No. 2, 1958
The Control of Human Fertility, by Sir SOLLY ZUCKERMAN.
The Use of Oceanography, by G. E. R. DEACON.
Technology and Product Design, by JOHN GRAY.

Vol. IX, No. 3, 1959
Grafting for Productivity in Plants and Animals, by PIERRE BOITEAU.
The Development of Optics and its Impact on Society, by VASCO RONCHI.
Teaching the History of Science, by RENÉ TATON.
Scientific Problems and the 1959-65 Seven-Year Plan in the U.S.S.R., by NORAJR SISSAKIAN.
The International Conference on Scientific Information, by PAUL BOQUET.

HOW LIFE ON EARTH BEGAN

by

A. I. OPARIN

210

Alexander Ivanovich Oparin, member of the U.S.S.R. Academy of Sciences, Professor of Biology at the University of Moscow, Director of the Bach Institute of Biochemistry of the Academy of Sciences. Professor Oparin's works are concerned with the biochemical principles governing the transformation of vegetable substances, questions of fermentation in the living vegetable organism, and problems of the emergence of life on earth.

231

The question of how life began is one of the supreme problems confronting natural scientists today, and one which interests every single one of us—even those unversed in science. But a rationally based answer has long evaded us.

Life is represented on earth by a multitude of different organisms constituting separate living beings. Our direct observation and experience persuade us that the only way in which any living creature comes into existence at the present time is by being born of creatures of a similar kind. This is true alike of highly organized plants and animals and of the most primitive bacteria, amoebae and algae. The views current for many centuries concerning the possibility of the spontaneous generation of particular organisms such as mice, insects, parasites and bacteria from inorganic matter (soil, putrescent filth and so on) proved false, being based on superficial observations and erroneous interpretation. Dirt and different kinds of refuse do not of themselves engender life but are usually merely the place or breeding ground where parasites and similar organisms lay their eggs, from which a new generation of living creatures emerges in its turn. In the same way, bacteria and other microbes are not spontaneously produced through the decomposition of particular products, decoctions or infusions. As was demonstrated as far back as the end of the last century by the well-known French scientist Pasteur, live embryos of certain micro-organisms are very easily deposited, from the air or otherwise, on products and liquids which are liable to decompose and ferment and so become a source of infection. They then produce a new generation of microbes, the life activity of which again gives rise to putrefaction or fermentation. Thus, while we see in nature long series of generations of living creatures, the origins of these series lie buried in the depths of time and are not directly perceptible.

A study of the fossilized remains, preserved in the earth's crust, of living creatures which inhabited our planet in the remote past has shown that the earth has not always been inhabited by the same forms of living creatures.

Time was when the living population of our planet was far less varied than it is now, and when the individual representatives of the animal and plant world were far more simply organized. The corollary is that the ancestors of modern organisms were not created in the far-off past in immutable form and by a single act of creation but arose as a result of continuous development from far less complex living creatures. At the same time, the further we go back into the depths of antiquity, and the older the fossilized remains we study, the simpler we shall find the creatures that inhabited the earth.

In this way, descending step by step, we shall finally arrive at that remote time in the existence of our planet (somewhere about 1,000 million years ago) when it was inhabited only by the most primitive organisms, the progenitors of all terrestrial life. And it is at that stage, in fact, that the question arises of how these initial organisms originated.

We now know that the only way the most primitive living creatures could have originated was by successive development from as yet inanimate matter. Thanks to the mass of factual material accumulated by the natural sciences during the present century, it has been possible to form a clear picture of the successive degrees or stages of development whereby the evolution of matter proceeded in the emergence of life on our planet.

The soundest procedure for studying this development is to begin by investigating the problem of the original formation on our planet of the simplest organic substances. Without these, life, as at present, is totally impossible and unthinkable. All living creatures, without exception, essentially consist of these substances, and the phenomenon most characteristic of life —metabolism—is possible only on the basis of the transformation of organic compounds.

To solve the problem at issue, therefore, the necessary first step is to get a clear idea of how hydrocarbons and their simplest derivatives—i.e., those carbon compounds which later went to the making of all the other organic substances (however complex) constituting the material basis of life—originated under natural conditions in the process of the formation of our planet or during the initial periods of its existence.

This first stage on the road to the emergence of life was still regarded, even a comparatively short while ago, as being quite beyond the scope of investigation and understanding, for it was assumed that, under natural conditions, the transformation of the inorganic forms of carbon compounds (such as the carbon dioxide in the air) into organic ones took place only through the medium of living creatures (biogenetically). This view was suggested by studying conditions as they exist on the earth in our own times.

At present, the overwhelming mass of organic substances are formed biogenetically through the agency of living creatures. Green plants absorb carbon dioxide from the air and use this inorganic form of carbon to create the organic substances necessary for their life and growth; and animals bor-

row these substances from them either by consuming them directly or by eating the bodies of other herbivorous animals. The whole of the living world now makes use in this way of organic substances produced biogenetically. This explains why many naturalists at the beginning of this century flatly rejected the possibility of the primary formation of organic substances.

But a searching study of this question has revealed that the biogenetic process of formation of organic substances is merely a particular case characteristic only of the contemporary period of the existence of our planet, for on all the celestial bodies now being studied there is evidence of the presence of hydrocarbons which must, there, have been formed by other than biogenetic means—i.e., entirely independently of living organisms. This leads us to doubt whether organic substances were always formed, even on earth, by purely biogenetic means. On the contrary, it is reasonable to think that on our planet too the simplest organic substances were formed independently of organisms, and before they arose, at a certain period of its existence. Confirmatory evidence of this is the fact that even today, when the bulk of the earth's surface carbon is involved in the biological process, geologists have been discovering hydrocarbon gases and slight traces of liquid carbons in clefts in the granite in the deepest lying rock strata; these could only have been produced there by other than biogenetic means.

A study of the history of the formation of the earth shows that it was precisely in that way that vast quantities of the simplest organic substances originated on its surface during the process of its formation and the initial periods of its existence.

The age of the earth as a planet has been set by various authors at periods ranging from 3,500 million to 5,500 million years, but the period during which life has existed on it is reckoned at from 1,500 million to 2,000 million years. It follows that our planet has been without life during the greater part of its existence. The hydrocarbons and their simplest derivatives began to appear on its surface from the very beginning of its formation. But they were only the initial compounds—the first link in the long chain of transformations which took place on the surface of the still lifeless earth and which led to the emergence, in its atmosphere and in the water-cover (hydrosphere), of a large number of varied and sometimes highly complex substances similar to those now included in the physical composition of animals and plants.

Not long ago, the American research worker Miller, by passing weak electric charges through a mixture of methane, hydrogen, ammonia and water vapour (thus artificially reproducing the conditions prevailing in the earth's original atmosphere), obtained amino-acids, the substances forming the basic components of the albumin molecule. The Indian scientist K. Bahadur has obtained amino-acids in a similar way through the action of sunlight—an experiment we have refined at the Bach Institute of Biochemistry.

The Japanese scientist Akabori has shown that by combining amino-acids (or, more accurately, their immediate predecessors) in conditions similar to those which existed when the earth originated, it should be possible for albumin-type substances to form. And contemporary literature is full of data indicating the possibility of the primary formation of other complex organic substances also. These substances originally occurred in the waters of the seas and oceans existing at the time, in simple form, as solutions, with a complete absence of form or structure. But when solutions of albumins and other similar organic compounds are intermingled, a separation of certain semi-fluid, viscous formations occurs; this is known as coacervation. For example, if we mix solutions of gelatine, egg albumin or similar albumins in certain conditions, the previously clear solutions will become turbid and it will be possible to distinguish under the microscope small, sharply defined droplets afloat in the water. These are coacervates.

The whole of the albumin substances previously found in the solution will have been concentrated in these droplets.

Despite the fact that the droplets are liquid, they possess a definite internal structure. The particles of substance are arranged in them not haphazard, as in the solution, but in a definite regular pattern. In other words, the formation of the coacervates is accompanied by the beginnings of a degree of organization, though admittedly a still very primitive and extremely unstable one.

This organization, nevertheless, is already of very great importance for the droplets endowed with it. Any coacervate droplet in a solution of given substances is capable of taking them up. They combine chemically with the substances contained in the actual droplet, in which the processes of integration and growth consequently occur. But the integration process in any given droplet is always accompanied by its opposite—the process of disintegration. Depending on the composition and internal structure of the droplet, one or other of these mutually conflicting processes will necessarily be more rapid and predominant. Let us assume that coacervate droplets appeared in some corner of the primal ocean, as a result of the mingling of solutions of albumin substances, and try to trace what happened to them. The first point to be borne in mind is that they floated not merely in water but in a solution of various substances. They took hold of these substances, combined them with the substance of which they were themselves composed, and in that way grew larger. The rate of growth of the individual droplets was not, of course, uniform. It depended on their internal structure and organization, but even from the start of their formation there were structural differences between them. And so some of them grew more quickly and others more slowly.

Furthermore, where the internal organization of a particular droplet was such that the disintegration processes became predominant in it, it was bound

sooner or later to break down and disappear from the face of the earth. In this way, all the chance emergent forms of organization which were 'unsuccessful' from that point of view automatically dropped out of the process of the further evolution of matter. It was only the dynamically stable coacervate droplets—those whose organization allowed the processes of integration to outbalance those of disintegration and resulted in the coacervates' continued growth—which were able to remain in existence for a more or less considerable time.

It was obviously impossible for each separate droplet to go on growing as a continuous mass: it broke up into daughter droplets similar in internal structure to the parent droplet but each of which, on leaving the other, started growing and changing independently; and so the process began anew.

All the unsuccessful forms of organization succumbed and disintegrated, and only the most perfectly constituted droplets were preserved for further evolution.

In this way a singular form of 'natural selection' of coacervate droplets arose in the process of the emergence of life. With the ever more rapid growth of coacervates on the earth's surface, therefore, there was not only a gradual increase in the quantity of organized substance but the quality of the organization itself underwent continuous improvement and refinement. This resulted in the adaptation of the internal structure to the performance of specific functions which is so characteristic of the organization of all living creatures.

It was some 1,500 to 2,000 million years ago that the coacervate droplets developed into primary organisms of the most primitive kind; but because of the fact that a qualitatively new and perfected sequence of chemical changes had now begun in them, their further evolution started to proceed at incomparably quicker rates. Whereas it took thousands of millions of years for life to emerge, the periods for major advances in evolutionary development began to be numbered thereafter in hundreds or even only tens of millions of years. To judge of this, we can take as a yardstick the organization of metabolism in the most primitive types of living creatures today and the fossilized remains of bygone organisms. Initially, the primary organisms' sole source of nourishment could only have been the organic substances previously produced abiogenetically from hydrocarbons. But the development of life proceeded more rapidly than the formation of these substances, the supply of which became insufficient. This change in the conditions of existence favoured the development of types of organisms which had become able, through their acquired ability to absorb light, to rebuild organic substances from inorganic carbon compounds and from the carbon dioxide in the air. This resulted in the emergence of a new biological method of synthesizing organic substances—photosynthesis—in place of the former very imperfect and slow abiogenetic process. It operated through a highly

perfected form of metabolism and proceeded in consequence to assume the paramount importance and monopoly role which it has retained up to this day. Practically all of the organic substances on the earth's surface are now produced biologically only, and the old abiogenetic method is completely without significance. Only with great effort is it possible to discover traces of the abiogenetic formation of organic substances in the earth's crust today. The emergence of photosynthesis—that supremely important event in the process of the development of life—occurred about 800 million years ago, and it produced a radical change in the general conditions of life on earth.

Some of the organisms themselves now began to build up the organic compounds they needed, while others retained their previous form of nourishment, taking advantage of those organic substances which were now also being produced biogenetically. It was on this basis that a division of organisms took place to form the plant and animal worlds.

The progress in metabolism was closely accompanied by an evolutionary development in the structure of living bodies. The fact that the first living creatures still lacked a cell structure is beyond dispute. Cellular structure appeared only at a particular and later juncture in the evolution of matter and was an extremely important stage in the subsequent development of life, leading to the emergence of a variety of unicellular creatures similar to the smallest of the algae, bacteria, amoebae and so on, that we know today.

A major step forward in the evolution of life was the appearance of multicellular organisms, thus providing the necessary conditions for the ever-increasing differentiation of the living body into parts, and the isolation of those parts into organs with different physiological functions; living organisms started becoming more and more complex and varied.

Life 500 million years ago was concentrated almost exclusively in the seas and oceans but it was already represented there by a diversity of multicellular as well as unicellular algae, and by living creatures including jelly-fish, sponges, the Annelida, Echinodermata, trilobites and other invertebrates. The first vertebrates (fish) did not appear until 100 million years later. But it took only another 150 million years for luxuriant forests of gigantic ferns, horsetails and club-mosses to grow up on the dry land (during the so-called carboniferous age) and for amphibians to come into existence. These were followed somewhat later by reptiles, which developed in particular abundance during the Jurassic and Cretaceous ages, about 60 to 70 million years ago. Altogether, only 35 million years have elapsed since birds and beasts appeared. However, the mammals of that age were still far different from ours, and it was not until a few million years ago that they acquired the familiar characteristics we know. And a total interval of only 1 million years divides us from the emergence of our remotest ancestor: his development lasted for a few hundred thousand years and led to the emergence of the human species proper, with a structure no different from that of modern man.

But man's appearance was accompanied by a new social form of the movement of matter which overshadowed its old biological form. And now the development of man's social life is already the determining factor for further progress.

This development, which is conditioned by its own specific laws, has now begun to proceed at rates far exceeding even those of biological development.

Arthur Compton once put forward an interesting chronological table in which the time-scale was condensed 1 million times, so that each second recorded on it corresponded to 1 million seconds of actual time.

Even with this scale, the periods required for abiogenetic and biological development amount to millennia and centuries, and therefore far exceed the range of time which we, with our brief life-span, are able to conceive of directly. But even so, how ridiculously short does the history of mankind in general appear, on Compton's scale!

Reckoning from noon today, it was only about a year ago that the ancestor of primitive man began to use crude stone tools. Then came the acquisition of speech. A week ago, man learned how to grind and polish stones. The day before yesterday he started using simplified drawings for symbolic writing, and only yesterday the alphabet was invented. The art and science of ancient Greece flourished yesterday afternoon, and at midnight Rome fell. This morning, just after 8 o'clock, Galileo observed his falling bodies. The first steam-engine was constructed about 10 a.m., and at 11 a.m. the laws of electromagnetism were discovered. At 11.20, the telegraph, telephone and incandescent lamp were invented, and at 11.30 X-rays were discovered, followed soon after by the discovery of radium and the invention of wireless telegraphy. Motor transport has been used for a total of only 22 to 23 minutes, and it was only a quarter of an hour ago that air transport began. The atom bomb dropped on Hiroshima exploded at 11.54 a.m. and only a few seconds before noon, in the world today, the first Soviet artificial satellite began to circle round it.

The picture I have drawn of the emergence and subsequent development of life gives a concrete idea of how matter passes from one form of organization to new and higher forms. In this process, not only do new qualities arise and new governing laws take shape, but the characteristic feature of this successive development of matter is that with each new stage reached the rates of development sharply increase, and hence the general development of matter proceeds in time as if following a steeply rising curve.

We have seen, in fact, that the abiogenetic evolution of organic substances took several thousands of millions of years. With the emergence of life, development became far more rapid, and took only hundreds of millions of years.

A total period of only 1 million years was needed for the formation and biological development of man; while the social transformations, finally,

have been effected during the course of millennia and even as little as centuries. Today, moreover, we can easily perceive substantial advances in the development of human society over periods of decades only.

Failure to take account of the differences in these development rates, and attempts to ignore the distinctions in the organization of the movement of matter, have always resulted—as they still result—in the grossest of errors.

On the emergence of any new form of organization, the old forms continue to exist, of course, but their role in further progress becomes insignificant, since their rates of development are several times lower than those of the new form of movement. We have seen this from the example of the emergence of life, where the old abiogenetic methods of synthesis of organic substances faded into the background; and this is also true in respect of the transition from the biological to the social form of the movement of matter.

A few years ago, when I was in Paris attending an international science congress, a questionnaire was circulated among the participants which asked, as its main question: 'What, in your opinion, will men be like in 500 years time?' The reply of one very outsanding natural scientist ran more or less as follows: 'The development of man is proceeding so rapidly that in 500 years' time his intellectual superiority over modern man will be as great as man's present superiority over a cow!'

The fact is, however, that we always judge the future from a study of the past. Regarding the scientist's answer, therefore, it is worth remembering that not 500, but nearly 2,500 years ago there lived a man named Aristotle, and if we compare his power of intellect with the mental capacities of some of our contemporaries, the comparison will hardly be to the latter's advantage. The conclusion is therefore that man, as a personality and as a biological individual, has not grown so much 'wiser' during the past 2,000 years, or progressed and perfected himself in that respect. It is true, of course, that every modern schoolboy knows more than Aristotle. That is not to say, however, that he has managed to solve Pythagoras' theorem through his own intellectual efforts, or has himself established the law of universal gravity. The knowledge he possesses has been acquired with the aid of the secondary signalling system peculiar to man: through the medium of the spoken word, images or writing, thanks to the development of human society and the social form assumed by the movement of matter—a form far more perfect than the biological one and hence developing at an incomparably faster rate.

On the emergence of life, the protracted and complicated abiogenetic method of formation of organic substances that had previously prevailed lost all significance in the evolutionary process, being incapable of matching the speed of the new transformations of metabolism, so finely organized and hence so rapid. In the same way, the significance for man's progress of his biological development has now become inconsiderable in the light of the emergence of the new social form of the development of matter.

Biologically, there has been scarcely any substantial change in man during the last millennium, yet during that time he has acquired an unprecedented mastery over his natural environment. He can now move about the earth more quickly than any deer, swim under the water better than any fish, and fly in the air further and faster than any bird. And this is not because he has sprouted wings or developed fins or gills in the meantime: his acquired powers are the result of general social—not individual biological—development. We find proof of this at every turn—even, for example, in what would appear to be such a purely biological field as the increase in human longevity.

It took many tens of thousands of years and hundreds of millions of human lives before man was able to develop resistance to certain types of bacteria by biological means in the process of natural selection. But in the past twenty or thirty years alone he has made a tremendous leap forward in this respect.

In particular, he can today easily overcome the agents responsible for pneumonia or blood poisoning—a difficult matter for him not so very long ago. But the reason for his success is not that his organism has become biologically stronger in itself in that respect but that he now uses industrially manufactured antibiotics: and without that gift conferred by social development he would die from those diseases just as he did 100 or 200 years ago.

Those who, like the scientist referred to, see the future of man in terms of an extraordinary biological development, with his head growing to the size of a beer barrel, or the general run of mankind turning into a sort of intellectual superman, are therefore in error.

The broad highway of human progress now passes not by way of the biological development of the individual human person but by that of the development of his social life and the progress of the social form of the organization of matter.

THE PLACE OF LABORATORY ANIMALS IN THE SCIENTIFIC LIFE OF A COUNTRY

by
W. LANE-PETTER

Dr. Lane-Petter was formerly in general medical practice, and during the second world war he served in the Royal Army Medical Corps. Since 1949 he has been Director of the Laboratory Animals Centre of the British Medical Research Council. He is also Secretary-General of the International Committee on Laboratory Animals.

SCIENTIFIC PROGRESS AND HUMAN WELFARE

When one considers the scientific life of any country one is at once led to make international comparisons, and what becomes immediately apparent is that scientific effort is both widespread throughout the world, and very patchy. This disparity between nations is greater than can be accounted for by the diversity of national characteristics. It arises chiefly from inequalities in the economic status of different countries, for which historical events outside the scope of this article have been responsible. For an active scientific effort can only be developed on the basis of a prosperous economy. Those countries that were first able to build up their industrial and economic strength, often with the wealth gained through colonial expansion, have, therefore, inevitably made the greatest contributions to modern science, first in the physical sciences and much more recently in the biological ones.

By the beginning of the present century the contrast was obvious between, on the one hand, the highly developed countries, mainly of Western Europe and North America, and, on the other, the rest of the world. When it came to the turn of the underdeveloped countries to seek economic advancement, the methods formerly employed for colonial expansion of internal exploitation were no longer available, for the ends of the world had been reached.

Imperialism and colonialism are today generally considered dead, or at least dying. It would be untrue, however, to condemn them as systems without virtue or advantage for both sides. They have made possible the technology of today which, with its unprecedented capacity for producing wealth, draws its intellectual strength from scientific discovery, to which it gives economic support. The technology of the West has spread, even to the former colonial areas, where self-governing nations have recently arisen whose standards, though low in comparison with those of the richest countries, are yet higher than they were before they became colonies. The history of the last four centuries has some harsh and bitter pages, but there are glorious

ones too. The most striking present proof of this is in the expansion of the world's population, due almost entirely to declining death-rates, especially in the so-called underdeveloped countries; and this is the fruit of medical knowledge and the conquest of disease.

The problem of these underdeveloped countries is to find the capital to invest in their own economies. They have their own labour and natural resources, still in most cases far from fully exploited, and they have access to technological knowledge. But these are not enough. They must be supplemented by material help provided, as an obligation rather than as a beneficient gesture, by the countries that have arrived, and some of this help must be in the form of scientific development.

Turning now from general considerations to those of science, especially of biological and medical science, it can be stated that there is a need to exploit scientific resources wherever they are found. These resources are, in the first place, human brains of a quality rare enough not to be squandered; and, in the second place, the tasks on which to employ the brains, many of them in the medical, and especially the clinical, field. No nation or race has a monopoly of brains, and no significant differences in basic intelligence are demonstrable between any of them. Furthermore, the altogether exceptional brains that go by the name of genius are so rare as to follow no statistical pattern in their distribution, and so valuable to mankind that to waste them would be unthinkable in a sane world.

Some of the most urgent problems facing science today are medical ones, and their urgency is likely to be felt in parts of the world least able to undertake their investigation. It is possible from time to time to institute crash programmes of research to meet urgent crises—the conquest of yellow fever in the Panama Canal Zone, and of scrub typhus in Burma, and the chemotherapy of malaria, are examples that spring to the mind—but in the long run the best results are achieved by laying down a credit, so to speak, of knowledge gained by fundamental research. Such a credit can be relied upon to pay dividends in terms of human welfare that are often astonishingly high. The discovery of penicillin was the result of brilliant fundamental research, which was then brilliantly exploited for the benefit of mankind to an extent that all the world knows. This discovery was within the discipline of bacteriology, which, like many other branches of medical and biological science, would not have been a science without the aid of laboratory animals. The exploitation necessarily used more animals, especially mice, and could not have succeeded without them.

It is not the purpose here to develop this theme, for it is sufficiently well known and can be taken for granted. Nor is any person likely to question the desirability of furthering medical knowledge by all available means. Since past advances have, like penicillin, been made with the irreplaceable help of laboratory animals and are likely in the future to be augmented by the use

of more laboratory animals, it would be ungrateful to the animal world and culpably perverse to deny these animals their necessary place in the scheme of medical and biological research. Unfortunately, however, the history of medical science and the practice of it today have too often overlooked this fact, and the laboratory animal has tended to be relegated to a position outside and inferior to that of the laboratory. Happily, on the other hand, the unwisdom of this relegation is now beginning to become apparent, and the purpose of this paper is to hasten the revelation. Its thesis is that the health, wealth and happiness of man, which everyone admits depend on a sound material economy and also on a lively and progressive scientific effort, look not least to medical science for their realization; and that, this being so, it must be fed with the very stuff of medical research, good laboratory animals.

THE COST OF BIOLOGICAL AND MEDICAL RESEARCH

In the previous section attention was drawn to the enormous disparity in economic development between the 'advanced' countries and the 'underdeveloped' ones. The volume of research effort, in terms of actual expenditure per head of population, is, like technological status, closely linked with the state of development of a country, although there are some countries with a high level of economic development which make proportionately less research effort than others, less well off, but apparently more enlightened. (It is impossible, at least for a scientist actively engaged in pursuing his scientific activities, to exclude all reference to abstract values, and no apology is offered for not even attempting to do so. They colour his whole outlook, and this fact might as well be admitted openly as falsely concealed. Those whose values may differ from his can then make their own adjustments to his arguments and conclusions.)

Since the present discussion is about laboratory animals, the fields of research considered will naturally be limited to those in which animals are important tools. It is necessary to use animals in the study of living processes, especially in relation to the health of mankind and, to a lesser but still important extent, to that of animals that are of economic value to man. This means medical research and those other branches of scientific inquiry closely allied to it, such as veterinary research and some aspects of biological research.

In spite of the enormous advances in medical knowledge that have been made in recent decades, disease is still a major cause of human waste and misery in most countries of the world. That a few countries have been able to improve the national health and thus prolong the average expectation of life by a factor of two or more only serves to emphasize how near the beginning of the road remain so many other countries. The cost of maintaining a high standard of health is, however, high. In Great Britain it is about £15

to £20 per annum for every man, woman and child, but even at this figure it is a good economic investment, quite apart from its contribution to happiness and well-being. The underdeveloped countries, however, are still crippled by their burden of ill-heath arising from starvation and disease, and they are less able to continue to bear this burden. Improvements in, and maintenance of, health are costly, but ill-health is even more so.

The amount of money allocated to medical research is only a small fraction of that which is, and should be, spent on the application of medical knowledge. Nearly fifty years ago the British Government put aside one penny a year for each employed person, amounting to a total of some £50,000, and formed a Medical Research Committee (which later became the Medical Research Council) to spend this modest sum. Today, in the same country, something under 1 per cent of the country's medical bill is spent on medical research, and this in a country where the medical bill, though high, is still lower than either the tobacco or the alcoholic drink bills.

Today the British Medical Research Council disposes annually of a little over £2.5 million. Substantial sums are also spent by other bodies on medical research. A complete breakdown of such a figure is not relevant to the present discussion, but some idea of how much of it may be expected to go on laboratory animals may be useful.

In the National Institute for Medical Research much effort is devoted to fundamental research. In such circumstances one might expect the animal bill to be comparatively high, and this is in fact the case. About a quarter of the total salaries bill for technical (non-graduate) staff is for the animal division, and about a third of the supplies bill. Something like 10 to 15 per cent of the cost of the institute is accounted for by the animal division. This is higher than it was many years ago, but at that time there were very many causes of dissatisfaction and frustration attributable directly to animals of poor quality. A deliberate and by no means inexpensive programme was initiated to raise the standard of the animal division. No cause has yet been found for regretting this policy; on the contrary, it has proved a wise one, whose expense is fully justified by results.

In another organization, where there is less fundamental and more applied research, as well as routine toxicity testing, bio-assay and screening of new compounds, the figures are rather different and expressed in another way. For every £100 spent on a scientific project, £25 constitute the salaries of graduate staff, and £6 to £9 the total cost of providing them with the animals they use for their work. A further examination of the figures from which this information is drawn shows that the more routine, simple and 'chemical' the use that is made of the animals, the lower is the animal bill.

This can be taken a stage further, if we consider a pharmaceutical manufacturing company carrying out almost stereotyped animal tests in circumstances that make for the greatest efficiency in providing the animal facilities.

Here the cost of the animals may be under 5 per cent of the total cost of a project, all overheads included. Overheads are much more liable to appear in their full stature in a business organization, where cost-accounting has constantly to be done, and some allowance for this may be made in considering the above discrepancies. Nevertheless, these figures, for all their incompleteness, show that laboratory animals account for a substantial proportion of any research budget—anything from 4 to 15 per cent and occasionally more—and due notice has to be taken of this fact in planning.

The planning of animal facilities is, in fact, a rock on which a new research institute can easily founder. If the necessity for spending up to 15 per cent of the total budget on providing animals has been amply demonstrated, as it has in countless organizations, it must be expected that not much less will have to be spent on the quarters in which they are to be raised and kept. For reasons which become evident in the next section, the standard of laboratory and animal accommodation to be aimed at is nearer to that of a hospital than of a farm, and terms like 'farm' and 'stable' should not be found in the vocabulary of this discipline. In the past it has been customary in many countries to purchase the common laboratory animals from commercial breeders or dealers who regard this as a business enterprise rather than as a scientific service, and this situation obtains today to no small extent. In other countries, such commercial suppliers do not exist or are of negligible importance, and laboratories have always been compelled to raise all the animals they need on their own premises. There are also to be found throughout the world animal breeding stations run by governments or by substantial organizations more or less under the control of the scientific faculties that wish to use the animals. Today, in most countries where commercial breeders have been important, there is a tendency for them to be gradually supplanted by breeding by or under the control of the laboratories, and this tendency is likely to grow as breeding becomes more of a science and less of a craft. The reasons advanced in favour of the system of commercial breeders are that they are there, already established, and that their animals cost less than animals bred in the laboratories would cost. This is in the main true, but both these arguments are becoming increasingly open to question. The presence of established commercial breeders is a convenience, provided that their animals are good enough for the purposes for which they are to be used. But the great need today is not so much for more animals numerically, although this is certainly part of the need: it is especially for better animals. The established breeder is already, it must be presumed, producing the best animals that his equipment and methods will allow, and too often they are not good enough. If he is to improve to keep up with the times, he must invest new capital and be reasonably sure of a sufficient return on his investment. The new capital equipment is of the same kind as would be necessary for the laboratory to

establish its own breeding facilities, under its own direct control, and will cost as much. If the money has to be invested, therefore, and it will be a considerable investment, it is probably safer to invest it directly than through the intermediary of an agency whose main interest is to make a commercial profit.

The experience of many laboratories is that the extra cost and trouble of breeding their own animals, or obtaining them from sources under their direct control, is more than made up by the better quality of the laboratory raised animals. A British laboratory has found that, for quantitative work in particular, one of its own guinea-pigs will do the work of four purchased animals, and that for some work only the home-bred animal will serve; and this is so, despite the fact that there is an ample supply of guinea-pigs from accredited commercial breeders, guinea-pigs which in other laboratories are fully satisfactory for qualitative work and cost less to purchase than the laboratory guinea-pigs cost to breed. Purchasing in the cheapest market can be false economy.

There are many other arguments that can be brought forward in this connexion, on both sides, but the balance comes down in favour of the above summary. Almost every country that is developing its animal facilities is adopting the direct system in preference to the indirect, although in a few countries the established commercial breeders are sometimes making a great effort to bring their plant into line with modern requirements. Only time can show whether they will be successful.

The animal division of a medical research institute, then, both that part devoted to breeding and that part set aside for housing experimental animals, will account for a tenth or more of the capital expenditure. Its equipment will be less costly than that of most laboratories, but the figure will still be high. It has been the bitter experience of many that this consideration has too often been overlooked. In the planning, any surplus on the over-all budget has been grudgingly given to the animals, which have suffered on the way by any economies that are forced upon the planners. The end result is like a fish without a tail; it does not swim very well. The wise director takes his 10 or 15 per cent at the beginning and builds his animal house before his laboratory. He can then establish it while the laboratory is being completed, so that his staff can move in when the painters move out and have animals ready to hand.

LABORATORY ANIMALS TODAY

The tremendous advances that have been made in recent years in medical research, and in the prevention and control of disease, owe much to the use of laboratory animals. Indeed, in the study of living processes the

animal is a necessary reagent or tool, and the very successes to which it has contributed so notably in the past ensure for it in the future a place of equal or even greater importance.

As any branch of natural philosophy matures into a scientific discipline, there is added to the exercise of qualitative observation the need for mensuration. So with the experimental use of animals. In an increasing degree animals are used not merely to give an answer to the question 'How?', but also to 'How much?'. They are not only indicators or detectors, but also calibrators. But calibrators must themselves be calibrated, and this raises a peculiar problem with animals. Before discussing this, however, it is necessary to give some information about the nature of the general problem.

During the last three years, in something over fifteen countries throughout the world, surveys have been carried out of the production and utilization of laboratory animals. Some of the surveys are more complete than others, and most have been consolidated in roughly comparable form and made available to those interested. Certain facts emerge from these surveys. In nearly all countries mice account for the great majority of animals used, even as much as 70 per cent in many cases. In only one country so far surveyed, Turkey, was this not the case. Here the most used animal was the guinea-pig, and this could be accounted for by the absence of a well-developed pharmaceutical industry and the paucity of cancer research laboratories which use a lot of mice, and in the activity of a public health laboratory service which uses a large number of guinea-pigs for the diagnosis of tuberculosis and other infections of man and cattle.

Next to the mouse comes the rat, accounting for anything from 10 to 25 per cent of the total and, closely following, the guinea-pig, which occasionally takes second place. After these three species, chickens, rabbits and amphibians come in roughly equal numbers. Less than 5 per cent of the total—in some cases only 2 or 3 per cent—covers all other species put together.

A study of the purposes for which each species is used is also illuminating. Mice are used in cancer research, but not in enormous numbers; in toxicity testing and the assay of drugs and other therapeutic substances, in the screening of new compounds for possible therapeutic usefulness and, in relatively small numbers, for a wide variety of research purposes. Toxicity testing, assay and screening are largely the province of the pharmaceutical industry, and together consume the largest numbers of mice; so much so that the numbers used are a good measure of the size and importance of that industry in any country's economy. Rats are also used in the same industry, but to a lesser extent: they find a place in nutritional and endocrinological research, in cancer investigations and in a wide variety of other research fields. Guinea-pigs find their main use in clinical pathology, es-

pecially in the diagnosis of tuberculosis and, to a smaller degree, of brucellosis. Their numbers are a fair indication of a country's tuberculosis eradication programmes in man and cattle. Thus, in the United States of America the guinea-pig peak occurred about twenty-five years ago; Great Britain has passed its peak since the second world war; Turkey, already mentioned, is at the height of its guinea-pig utilization; and in India we can expect the demand for guinea-pigs to rise as the drive against tuberculosis develops to its full capacity.

In Great Britain, where two very thorough surveys have been carried out for the years 1952 and 1956, and where other figures are available for reference, the total number of all species (of vertebrates) used is rising by about 8 per cent each year; but in contrast guinea-pigs are falling by about 3 per cent. No such figures are available for any other country, but reasonable estimates can often be made. A growing pharmaceutical industry will call for greatly increased numbers of mice and rats. Cancer research demands the same two species, but in smaller numbers and with a greater diversity of strains, and this demand is closely linked with that of radiobiology. Nutritional studies ask for more rats, and also perhaps chickens and a few other species. Physiological research uses small numbers of animals of many species, especially dogs, cats and some farm animals. Thus, by studying surveys already completed, and particularly the breakdown tables that they present, needs can be forecast with considerable confidence, and steps taken to anticipate them.

Certain special cases require mention. Monkeys, dogs and cats are used in comparatively small numbers. The great majority of monkeys are used for the production and testing of poliomyelitis vaccine and so long as present methods of vaccine production and testing continue this demand will increase. Almost all the monkeys used are captured in their wild habitats in India, Siam, the Philippines, West, Central, South and East Africa, and have to be transported by air over long distances. The problems of catching and transporting them, involving care in conditions of captivity and especially in transit, are many, but in general the traffic is successfully and humanely conducted. There are exceptions to this, but the co-operation of all interested parties can, and to a large extent has, overcome most difficulties, and the losses of these animals between capture and use are each year diminishing.

Dogs and cats are for the most part collected, as unwanted strays, in urban areas. The numbers used are not great, nor are they growing to the same extent as those of the small rodents, but they raise special difficulties. In many countries there is a substantial public opinion opposed to the use of stray dogs and cats in the laboratory, and in not a few this public opinion is both vocal and influential. The fact that it is irrational makes it none the less a hard fact that has to be taken into account in any system

of procurement, and in those countries where this is so difficulties are experienced that are material, if sometimes exaggerated.

Generally speaking, however, any difficulties that are met in providing laboratories with the animals they need are of internal rather than external origin. One such difficulty has already been indicated in the previous section: the reluctance to set aside a sufficient proportion of the budget for the provision of animals. Past tradition, even of the standing of a decade or two, dies hard. When, for years past, the procurement of animals has customarily been left to casual initiative, often on the part of the most subordinate members of the staff, it requires a considerable, even a painful, revision of attitude for animals to get on to the agenda of top management. All of us know physiologists who at 6 o'clock in the evening will chalk on the blackboard of their laboratory their requirements for the following morning: 2 cats, 3 rabbits; or the bacteriologist who gives a few days' notice of his need for 500 15gm. male mice—'Swiss albino', as likely as not—for an experiment he has been planning and preparing over a period of months. That their demands have, in the past, somehow been met only makes them the more indignant or bewildered, according to their individual temperaments, when today they are told that there are difficulties. Understandably, they do not want to know about the difficulties; they just want to have the animals and get on with their work.

But the difficulties exist, and it becomes the duty of someone to know about them, study them, and meet them. This is indeed a problem within the field of biological science, and it is no surprise to find that it is susceptible of solution by the methods of biological science. Although the animals obtained must be paid for, for their provenance is not gratuitous, this is not, most emphatically, a problem of commerce. The provision of suitable laboratory animals, in sufficient numbers, when and where they are needed, has become a subject of study in its own right. Animals have no shelf life; they grow and pass rapidly through their period of usefulness, never to return; they become sick and unfit for use; and they can display a fickleness in their ability to reproduce that is the despair of those who breed them.

Animals also show a tendency to variability, due to their genetic make-up, or to the vagaries of their environment, or most often to a combination of both. This variability is, for most purposes, one of the things least wanted. Laboratory animals have often been compared with chemical reagents, whose constant relationship with the label on the bottle can be relied upon. It would be convenient if all strains conformed as closely and as constantly with the standardized designation by which they were identified, but this is, unfortunately, an illusion that can seldom be nourished by a critical mind, and never for long. The term 'Swiss albino' once referred to a restricted strain of mouse; but it has today become so plagiarized that it no longer

bears any exact meaning beyond the fact that its bearer has a white coat; and a white coat is no more a guarantee of purity in a laboratory mouse than in the scientist who uses it. Again, the overworked term 'pure line' in this connexion no longer has any real meaning, if it ever had. It derives from a conception that is more appropriate to the chemist, who can talk about purity in a measurable sense, than to the biologist.

There are two factors, and only two, that determine the nature of an animal. The first is its heredity or genetic make-up, controlling its genotype, which is settled once and for all at the moment of conception. The second is the environment to which it is subjected from that moment onwards, and this includes not only the external environment—such as temperature, ventilation, humidity and other conditions of its confinement—but also the internal environment—such as its state of nutrition and the micro-organisms, both pathogenic and non-pathogenic, which it harbours or with which it comes into contact. The actual animal displays a phenotype which is the result of the interaction of genotype and environment, and it is the phenotype which is of direct interest to the majority of animal users.

Now, if these two factors, genotype and environment, contributed independently to the phenotype, a reduction in the variability of either one would result in a greater phenotypic uniformity in a group. But the contribution of the two determining factors is not independent, but interdependent. Genetic manipulation, that is, the application of genetic principles and techniques, can reduce the genotypic variability to a very low degree, almost to vanishing point, but at the same time it can, and often does, confer a corresponding lability upon the animals that may make them more sensitive in their responses to small environmental changes than their more genetically variable cousins. This is particularly so when the environment departs from the optimum; a poor environment, even if uniform, provokes variability in phenotype. Genetic uniformity in a strain that has been closely inbred with this object in mind also tends to reduce vigour and fertility, leading to special problems of maintaining such inbred strains. Vigour can often be restored by outbreeding, thus destroying the genetic uniformity; and the restoration and destruction are achieved in a single generation.

There is one way in which it is theoretically possible to have the best of both worlds. Any animal receives exactly half its genes from either parent. If the parents come from genetically uniform but different strains, each will contribute an exactly similar set of genes, the sex-determining chromosomes excepted, to all their offspring, and so will all the other members of the same, inbred, strain. The first generation cross between such strains will therefore have identical genotypes, while having the vigour conferred by outbreeding. It will not of course be possible to repeat the process by further breeding from this first generation cross, because segregation and

recombination of genes will give a variety of genotypes in the subsequent generations. The production of their first generation crosses is thus dependent on maintaining two inbred strains to provide the parents.

There is a further complication, due to the fact that from time to time there occur in the genetic make-up of all animals (and plants, too) changes or mutations that can affect the genotype and thus the phenotype, often profoundly. Such mutations, if recognized, can be bred out, if it is desired to do so, but no known manipulation can prevent them from occurring; on the other hand, their frequency can be increased by various means, such as exposure to ionizing radiation and other mutagenic influences. The maintenance of an inbred strain therefore requires not only close inbreeding, normally achieved by perpetual brother by sister mating, but also the elimination of mutations as fast as they are detected. On the application of these techniques depends the provision of both inbred animals and first generation crosses, both of which have their uses in the laboratory.

In one particular field of research, namely cancer, the animal requirements are for the most part highly specific. At the present time probably well under 10 per cent of all experimental animals are used in cancer research, and most of these are mice and rats. But as medical progress, through the conquest of age-old infections that have afflicted mankind, prolongs the expectation of life in ever more areas of the world, a higher proportion of its population is living into middle and old age; and it is in middle and old age that occurs the greatest incidence of cancer. Paradoxically, therefore, improved health leads to more cases of cancer, and presents perhaps the greatest challenge of all to medical science. It must be reckoned that the challenge will be met by a growing volume of cancer research, calling for more animals to serve it.

The experimental attack on the problem of cancer requires, more often than not, animals—mainly mice and rats—of clearly defined genotype, which can only be maintained in strictly inbred strains. Now, the technique of inbreeding is not quite so simple as mating together brother and sister, generation after generation, and harvesting the progeny. If the technique is faulty, an occasional mismating may destroy a valuable strain; alternatively, there may be no progeny to harvest, for inbred animals are notoriously less fertile than outbred. There are today at least eighty well-defined inbred strains of mice alone, and most of them have more or less differentiated sublines, but the cancer workers are continually asking for more strains from which to choose, and the number of established inbred strains will soon reach a hundred and twenty or more. Moreover, the production of sublines scattered through many laboratories is more of a drawback than an advantage, for the sublines may lose characteristics which were desirable in the parent strain, without gaining new characteristics which would add usefully to the diversity of choice. Already too much of cancer research workers'

time is taken up in maintaining and checking the special strains, and not seldom their work may be temporarily halted by the difficulties they run into. Few chemists today expect to have to make their own chemical reagents, and it is uneconomic and unreasonable to expect the experimental biologist to be similarly occupied. There is everything to be said for handing over the responsibility for maintaining colonies of cancer strains to specialists, who can supply authentic breeding stock and even, through the intermediary of production units under their control, experimental animals, so that the cancer worker can be more fully occupied with his proper tasks.

The control of the environment is of a kind quite different from genetic control. Environment includes all those influences to which the animal is subjected throughout its prenatal and postnatal life. Physical environment—temperature, humidity, and the like—is the most obvious element, but two further elements are of equal if not greater importance in determining the phenotype. The state of nutrition, which in prenatal life and during the nursing period means the nutrition of the mother, is fundamental. Too little food will result in small animals. Food that contains essential ingredients but in unsuitable proportions, or that is deficient in certain essentials such as vitamins or minerals, will lead to abnormal growth, deficiency diseases, infertility and death. A further element, infection, will also affect the quality of the animals and their fitness for experimental use. Too often experiments are frustrated partially or altogether by the death of the animals from intercurrent disease, arising from infection present from the beginning which becomes manifest under the strain of experimental use, or acquired before or during the course of the experiment. Some infections, such as mouse pox and mouse typhoid (which can also affect many other species), can wipe out whole colonies. Others appear to be latent and, while not always giving rise to epidemics, can so interfere with the experimental procedures as to undermine or render valueless the results. Easily recognized infections, though often severe in their effects, are perhaps least to be feared, for their recognition provides an opportunity for their control and elimination, and there are many colonies of animals today where serious epidemics are seldom if ever encountered. But latent infections pose a more difficult problem, because they, almost by definition, only reveal their presence in the course of experimental use, and their effects can be almost if not quite as devastating.

It should be borne in mind that modern methods of laboratory animal husbandry contribute substantially to the difficulties of ensuring adequate nutrition and freedom from disease. The custom of giving specially prepared compounded and compressed diets, superseding the mixed unprocessed foods of past years, is dictated equally by the desire for standardization of feeding and the need for hygienic and labour-saving régimes. The difficulty is to ensure that the formula chosen for a particular diet is, in the first place, a really complete one, meeting all the animal's nutritional needs; and, in

the second place, that the manufacturers always adhere to this formula. Both these difficulties exist today in many countries.

Again, there is a tendency, the reasons for which are self-evident, for laboratory animals to be raised in large numbers together, in order that demands may be met for large numbers of animals of similar background and characteristics. This tendency is economically sound, and is to be preferred in every way to the system of drawing animals from a large number of modest sources, where the genetic and environmental conditions will necessarily be highly diverse, and where the mixing of the infections coming from the various sources will play havoc at the receiving end. But the price of concentrating production is the creation of huge populations, which are an open invitation to the spread of epidemic disease and which present great and even insuperable obstacles to its eradication. This is one of the outstanding problems of laboratory animal production today, of which the solution is little more than a hope on the horizon.

Finally, in considering environment, must be considered the quality of care that is provided for laboratory animals. The most stable strains, offered the most complete food and kept in conditions of impeccable hygiene, will not thrive if those that look after them are inexpert. Once again, it must be stressed that we are not dealing here with chemical reagents, but with complicated biological organisms having a built-in pattern of behaviour that is highly responsive to the quality of human care. There is a need here for a class of person properly belonging to the category of technician, in the English sense of the term; that is, of non-graduate scientific workers specially trained in the techniques of looking after and handling laboratory animals, with a background knowledge of general biology and a special knowledge of certain fields particularly appropriate to the breeding and care of animals. Such people are today called animal technicians; as scientific auxiliaries they are indispensable, for the care of the modern laboratory animal requires a degree of special skill that has only recently been acknowledged. In several countries such technicians receive special courses of training and take examinations. Wherever this policy has been followed, the results, as measured by the quality of the animals, have justified it; elsewhere old and familiar difficulties remain.

THE IDEAL LABORATORY ANIMAL

It is clear, therefore, that the ideal laboratory animal, which the user would seek if possible to calibrate, has certain characteristics that can be postulated in detail, though not always realized. It must be of known genetic composition, conforming as nearly as genetical science can ensure to the title by which it is designated. It must be in a state of completely adequate

and balanced nutrition, and this state must be capable of being continued in all conditions that the animal is likely to encounter. It must be free of all infections that can give rise to disease or interfere in any way with the experimental procedures for which it is to be used. It should, if possible, have a high fertility and be easy to raise with due regard to economy. And, *sine qua non,* it must possess characteristics that fit it for experimental use; since the demand for these is almost infinitely protean it follows that a wide variety of animals, even of strains of a single species, must be available. All these, the basic requirements, have to be found in an entity that grows, reproduces and dies, generation following generation; that is, in a word, continually changing, and therefore cannot be standardized in the normally accepted meaning of the term. For standardization implies the ability to lay the entity alongside a fixed and unvarying standard for comparison, and this cannot be done with an animal. Once again, the contrast with chemical reagents is brought out.

The above postulates, however, forecast the solution of this problem, for they represent the basis of a description or specification which can be regarded as a standard, and to which an animal, or a group of animals, can be held to conform. It is possible to specify genetic composition, morphology, nutrition and infection status, and specific responses to test procedures, and to state whether a given animal or group of animals can be accurately so described. It is possible to do this, but in the case of any specification that is detailed enough to be useful it will occupy a considerable amount of scientific and technical labour, and in the process of finding out how far they conform to the specification the animals under examination will almost certainly be modified and thus rendered unavailable for experimental use. Such testing for conformity must therefore be done by the methods of sampling and production control and, in view of the labour involved, only small samples can be tested and checked. Moreover, the testing must be repeated indefinitely in time, because, as has already been explained, both the genotype and the phenotype are constantly liable to change.

All this points to a simple conclusion. Specifications have to be worked out in terms that are defined. Even before this can be done, definitions are needed that carry exact meanings universally agreed. Centres are required where colonies of animals that will conform to such specifications can be maintained and constantly checked for conformity. These centres must be staffed by scientists and technicians capable of exercising this control and, because such control is laborious and therefore expensive, the colony must be small. In fact, the animals that come out of these centres are of such value that it would be quite impracticable to use them directly for most experimental purposes. They must be regarded as the breeding stock for large scale production of experimental animals which, though unsusceptible to the direct control to which the primary type colony (as it may be called)

is subjected, will not, it is hoped, differ materially from their near ancestors. And indeed, they are unlikely to differ materially from the primary type colony, provided the conditions of subcultivation are carefully prescribed and rigidly observed, and resemble in every practicable way those of the primary colony, and the subcultivation is not carried on for more than a very few generations. If epidemic disease or any other catastrophe overtakes a completely self-contained colony a valuable strain may be lost beyond recovery, but if it occurs in a secondary production colony even total destruction is not irrecoverable; new breeding stock, conforming to the original specification, can be brought in from the original primary type colony and production recommenced.

THE MEANS OF IMPROVEMENT

So much for the mainly theoretical considerations. It is pertinent to ask to what extent practical effect is being given to them, so that medical research can ensure a supply of one of its most important basic materials.

In 1955, the International Union of Biological Sciences (IUBS) and the Cell Biology Group of Unesco independently recognized the existence of this problem on a world scale. Both made an attempt to enlist the help of scientists who had made a special study of this subject. As a direct consequence, there came into being, in December 1956, an International Committee on Laboratory Animals (ICLA) which today has the support of IUBS, CIOMS (Council for International Organizations of Medical Sciences), IUPS (International Union of Physiological Sciences), and Unesco. The first three international organizations support the work of ICLA by direct monetary grants, while Unesco provides substantial help by way of contracts for specific projects, provision for travelling and the holding of meetings and much assistance from the secretariat.

The tasks confronting ICLA appeared formidable, but one thing could be initiated without delay, namely, surveys of the production and utilization of laboratory animals in different countries, to which reference has already been made. This at least has provided some essential basic data; it has also had a gratifying secondary effect. It has been found that the mere carrying out of a survey has in many cases stimulated interest in the subject that was previously dormant, and also brought those scientists to whom this subject particularly appealed in contact with one another. A further consequence in a few countries has been the establishment of national laboratory animal organizations or centres where none existed before. All this is sheer gain, whose value to medical research is certain but incalculable. A chain of laboratory animal centres throughout the world, exchanging information as well as animal material, is already appearing.

The problem of fixing definitions and working out specifications can now be faced, although its solution will not come quickly. Universal agreement on this subject can only be reached through the work of international committees, but national laboratory animal centres must endeavour to assemble the data on which committee decisions can ultimately be based. There is a danger of creating theoretical postulates which are incompatible with reality, as represented by the nature of the biological material under consideration. A dozen strains of animals accurately described in detail and existing in properly organized centres are worth infinitely more than a hundred specifications, not one of which is realized. The lack of progress so far made by ICLA in working out definitions and specifications seems to support the thesis, beyond the possibility of argument, that the first need is for active laboratory animal centres, where animals of high quality are actually being maintained and their characteristics investigated. From these centres will come, as a result of experience, information on how the essential specifications can be built up, as well as detailed knowledge of what it is possible to specify and what is at present beyond the biologists' grasp.

As a corollary to this thesis is another need, to which almost every national survey has drawn attention: the need for skilled animal technicians. It is only slowly being recognized that such persons have to be trained in what is virtually a new discipline. It entails some knowledge of general biology, some familiarity with ordinary laboratory techniques, but above all a high degree of practical skill based on a special aptitude for handling animals. This new discipline has to compete with a damaging and out-of-date tradition that has relegated to the animal house those who were considered incompetent or unfit for employment in any other scientific capacity, and such a tradition, as always, is hard to combat. A programme of training animal technicians, taking advantage of the experience gained in the few countries where such training already exists, has been prepared by ICLA and will, perhaps, help others to develop similar programmes.

In a new field of scientific activity the importance of the exchange of information and of personnel can hardly be over-emphasized. Progress in different parts of the world is certain to be piecemeal, but it can be hastened and generalized if it is constantly compared. Contacts through personal visits of consultants; correspondence on current problems; grants for would-be specialists to enable them to visit advanced centres; symposia; information bulletins devoted to this subject; all these are among the means of stimulating progress and achieving results, and all are already undertaken by ICLA. ICLA consultants have visited most of the countries of Europe, in some cases on more than one occasion, in order to inform themselves on laboratory animal developments and to stimulate local interest in current problems and suggest solutions. Scientists in different countries who are specially interested in this subject are rapidly becoming known one to

another, through exchange of correspondence and by personal contact. ICLA has published, since September 1956, a half-yearly bulletin, containing reports on its work and information of general and particular interest in this field. Specialists, actual or potential, have been enabled to visit advanced centres, thanks to the facilities provided by governments and international organizations such as WHO, for the purpose of acquiring or increasing their knowledge of laboratory animals. An international symposium on living animal material for biological research was held with Unesco's co-operation in Paris in October 1958, and the proceedings are being prepared for publication. Unesco is also, on ICLA's advice, collecting information about regulations concerning the import, export and international transportation of animals. These and other active contributions, some of which have already been mentioned, are part of ICLA's achievements in a programme that is ambitious but realistic, and to which the response is everywhere generous and even enthusiastic because it is timely.

But the acid test of progress is whether medical research can eventually call on an adequate supply of laboratory animals of the quality that it is clearly going to need, and it is well to remember that no committee ever produced a single animal. However excellent its programme, however faultless the logic of its deliberations, neither ICLA nor any other international committee will be able to contribute anything of value, except through the agency of properly staffed and equipped laboratory animal centres which actually produce animals of the kind and in the quantity demanded. For the most part these centres would seem to be best set up nationally, for only occasionally will it be possible to finance them except out of national funds. Without something of this kind, a nation will find it difficult or impossible to support any medical research, for it would be like building a factory without having a source of raw materials.

The argument thus turns full circle. The wealth of a country is dependent upon many things, not least upon its health, and this in turn upon its standard of medical knowledge. Medical knowledge must be constantly fed or rejuvenated by research, and this demands animals that will meet increasingly exacting requirements. How these may be provided has been the main part of this discussion. Remove a single step in this circle of logic, and the ends fly apart, destroying the circle.

CONCLUSION

The title of this article was chosen so as to be quite deliberately provocative. It might, at first sight, appear even to overstate the case, but I have tried to show that this is not so. The analogy of the factory without a supply of raw materials is unfortunately too true to be comfortable, for it evokes a

picture of wheels turning and nothing coming out; or, worse still, because it represents so much more waste of human endeavour, the production of something that is without value. Such a situation may be just as true of medical research, and large institutes can, like the proverbial mountain, travail and bring forth a *ridiculus mus*; only in this case it may be the worthless mouse going in that leads to his metaphorical counterpart emerging. No country today spends all it needs to spend on medical research, least of all those that have little to spend on anything; yet the less there is to spend, the more necessary is it to spend it wisely. National wealth is notoriously no measure of national talent, but the exploitation of talent, whether at the level of genius or of plain competence, is largely dependent on wealth and the way it is employed. The cost of laboratory animals, the cost of medical research, and the cost of maintaining the health of the population are in steeply ascending order of magnitude. Wise policy begins at the beginning, which is also the cheapest end of the scale.

The world is short of geniuses, as it must always be, if the definition of genius is the extreme height of human intellect. The world is also full of problems, with never enough intellectual competence to solve them fast enough. Both the competence and the problems are distributed regardless of economic development, and they are best employed and tackled respectively where they are found. Whatever may be happening in certain scientific fields, medical science is, fortunately, not too much subject to the restrictions or delusions of international security. Rich countries would do well to remember that they do not have the monopoly of scientific potential, and that the resources they have at their disposal for medical research would be more profitably shared with countries less well endowed.

It would be nothing more than a policy of enlightened self-interest, for individual countries and for the world as a whole, if those countries that could afford to develop medical research invested a substantial proportion of their resources in other countries where facilities are poor but unrealized talent may be expected to be found and problems exist in abundance. Indeed, something of the kind can already be seen to be taking place in all parts of the world. Newly developing countries can call on a number of international agencies and organizations having very considerable financial resources that derive mainly from the richer countries, and the debt of history is beginning to be paid. Whether this process is on a large enough scale is open to question, but it cannot be held that medical research is being overlooked. New programmes are constantly coming forward for implementation and, if this is done wisely, results of inestimable value to mankind will certainly follow. But it is possible to spend these sorts of resources unwisely, as the history of benefaction can demonstrate. When a new medical research institute is to be created, or an old one enlarged and brought into line with modern requirements, it is surely only common

sense that it should be equipped with adequate animal houses, so that the medical research worker may be provided with good animals as well as good apparatus.

ACKNOWLEDGEMENTS

I am deeply indebted to all who have provided information on which this article is based. More especially I would like to thank those who supplied much detailed information about the working of their own laboratories, often of a confidential nature which precludes even the mention of their names. One in particular, however, must be recorded, namely Sir Charles Harington, F.R.S., Director of the National Institute for Medical Research, who not only gave figures which have been freely used, but who was also kind enough to read and criticize this article. To him, and to all the others, who bear no shred of responsibility for my opinions or errors, I am profoundly grateful.

THE PLACE OF OPERATIONAL RESEARCH IN THE DEVELOPMENT OF MODERN SOCIETY

by

J. LESOURNE

Jacques Lesourne is Professor of Economics at the Saint-Etienne School of Mining and Professor of Company Economics at the Demonstration School of the National Institute of Statistics and Economic Research. He has lately had a book published by Dunod, entitled Technique Economique et Gestion Industrielle.

For some years the branch of study known as operational research has been making rapid strides and, like so many other swiftly developing sciences or techniques, it is found somewhat baffling by the layman and even the specialist. Instances of its work or the mathematical curiosities it has produced stagger their imagination but leave them at a loss to assess the place of this new study in the development of society today.

The present article is an attempt to analyse operational research in this context, as the best way of elucidating its significance and outlining its future. The two points to be demonstrated are: (a) that operational research is not the fruit of spontaneous generation, but the outcome of a slow process extending over several decades, and (b) that the phenomenon of operational research is closely bound up with other aspects of modern society.

Finally, I shall try to give an idea, in broad outline, of the impact that operational research may have on the future development of society.

Everyone, or nearly everyone, regards operational research as a wartime creation of the Anglo-Saxon countries, as a discovery made by academic specialists working with the army. But to take such a claim at its face value is tantamount to dating the emergence of a particular outlook from the moment when its originality is so clearly realized that people think fit to give it a name. In other words, it means discounting the long period of maturation that went before.

To go back further than the end of the nineteenth century, the spirit of operational research may be said to be discernible even in Taylor's writings. Taylor's first papers were concerned with metal cutting at Bethlehem Steel. He discussed all the possible variations in the speed and depth of the cut, and in the shape of the cutting tool, and endeavoured to determine the best cutting methods either by rule of thumb or with the help of mathematical formulas prepared by specialists.

During the 1914-18 war Lanchester (whose name was later attached to

a prize in operational research) worked out equations for military operations, and some years ago these equations proved to be a satisfactory means of assessing the evolution of the battle of Okinawa.

At about the same time Pareto, working in a field having no apparent relation whatever to economics, gave final formulation to the meaning of the theory of the economic optimum which was to assume so much importance in France 40 years later.

The second decade of the present century saw the birth of commercial studies in the United States of America. The first market study is said to have been carried out somewhere about 1910-11 by the Curtiss Publishing Company, a magazine publishing house. Feeling itself at a loss for arguments to put over in its advertisements and having just bought up a new agricultural magazine, *The Country Gentleman,* it decided to study the market for this periodical by questioning farmers and the manufacturers of farm machinery and products about their needs and wishes. This first study gave the company a great fillip and was very well received by its readership.

And so, on all sides, definite trends began to appear independently and spread during the first half of the century until they gradually merged into a recognized body of thought after the second world war.

The year 1930 was marked by the establishment of the Econometric Society, whose journal *Econometrica* was largely instrumental in the development of modern economy. At the same time the growth of national accountancy opened up a new field of action for market research, survey and sampling techniques were perfected, and the calculation of probabilities and statistics assumed more definite form and ceased to be a field of knowledge confined to a small group of leading specialists.

But in this, as in so many other fields, the war was to hasten progress. In the United Kingdom, and later in the United States, the armed forces developed operational research and operations research units, whose principal forms of activity are too familiar to need recalling here.

In France, the nationalization of many branches of industry, coupled with Mr. Allais' efforts to popularize the theory of the economic optimum, prompted growing numbers of engineers to ponder on the management of large industrial concerns and to study the economic aspects of production, pricing and investment. The first step towards a unified approach to such problems came with the establishment of the Société Française de Recherche Opérationnelle; certain members of the founding group were mainly influenced by Anglo-Saxon research, others by French research.

At present, these various currents of thought that have sprung up since 1920 are merging together and modern management techniques are taking final shape. While it must be admitted that the terminology used to define them is still very confused, terms such as econometry, applied statistics,

marketing, operational research and management science may be said to denote approximate areas around which research or its applications have concentrated rather than clearly definable corpuses of study.

If we wish nevertheless to define the position of operational research in relation to other branches of learning, it would perhaps be best to adopt the following principle. Scientific thought has always followed a two-way course of development—that of pure or fundamental science, the aim of which is to perfect models enabling us to describe the concatenation of actual phenomena, and that of applied science (or technology), which helps us to define coherent practical objectives and suitable means of achieving them. The fundamental sciences and branches of technology have their points of contact, of course, since each branch of pure science gives rise to one or more branches of technology, while each branch of technology is in turn related to one or more of the fundamental sciences. We are now quite accustomed to this situation in the physical sciences, and are so well aware of the relative status of technology and science that we are apt to forget that some of the branches of technology began their development in advance of the relevant branch of pure science and to some extent independently of it. We are now witnessing the same process in the new sciences. In the case of pure science, scientific disciplines covering categories of phenomena are being built up, the most advanced of them being economics and psychology, whereas others such as sociology, administrative science, political science, etc., are only just beginning to come into existence. Until recently, these sciences had not given rise to any branch of technology. In other words, the counterpart to scientific thought in the field of applied science was a vast 'no man's land', the most accessible part of which was naturally invaded by different armies having the same aims but different backgrounds. Economic science has thus given birth to a technological branch that is sometimes known as econometry. In the United States and the United Kingdom, the pioneers in operational research have been the physicists, mathematicians, chemists and in some cases the biologists. Their armies are still encamped, pell-mell, on the same field, but having once taken up their positions, they have become increasingly aware of the importance of economic factors.

In time, the term 'operational research' may possibly be discarded, should the study fail to establish itself as a field in its own right once the exact relationship between the different branches of technology and the fundamental sciences has been finally determined.

A question often brought up in this connexion is the relationship between operational research, organization and the automatic processing of information. Organization would seem, basically, to be an administrative 'pre-technique' in that it was built up before administrative science and depends more on intellectual honesty and common sense applied to the observation

of facts than on scientific method in the strict sense of the term. Organization is therefore largely situated in our 'no man's land', in one of the areas still beyond the reach of scientific method. In the case of the automatic processing of information, on the other hand, the field covers the whole range of problems arising from the use of automatic computers. The latter, incidentally, are not at present used for more than one in every five or ten operational research studies.

The term 'operational research' thus covers a broad and deep-running stream of thought which has been gradually formed over the past fifty years and reflects the progressive advance of science into the realm of social problems.

Once operational research has been assigned its proper place in the stream of thought of which it is only one element, it is far easier to see how far it mirrors present-day collective thinking, the main features of which are readily discernible.

1. Scientific thought still has considerable power of expansion. The ideologies which have grown out of it are still dominant, and large numbers of men engaged in every field of research are prepared to renew each day, as a working hypothesis, their act of faith in the possibility of building up concepts and systems whereby all phenomena can be apprehended. The success of this method in physics, chemistry and biology is an obvious argument for applying it to the study of economic and social phenomena.

Yet this expansion of scientific thought has had to be fought for. For a long time it was halted by the lack of understanding paradoxically shown by two different classes of people.

For the layman, the scientific method seemed to amount to no more than plain intellectual honesty—an attitude that is responsible for the emergence of such inadequate expressions as the science of law, political science, and so on. For those with scientific backgrounds, the scientific method seemed inseparable from traditional physics, the only field in which disagreement between theory and fact was thought to be comparatively negligible by human standards. It was gradually realized that science was a harder taskmaster than plain intellectual honesty and that rather than being tied to any single discipline it involved the application in all cases of a single method—the construction of operative concepts and the elaboration of models. It was this realization, for example, that led to the discovery, from the conceptual standpoint, that just as in physics mass is a constant reflecting repeatable relationship, so the phoneme of the original Indo-European language family in fact represents the point of contact between clearly defined phonemes of languages such as Greek, Old Slavonic, Lithuanian, Persian, Sanskrit, etc. This definition of concepts has its repercussions on

vocabulary, and produces a progressive tendency to replace terms whose meaning is enlarged by refinements and ramifications of connotation by terms merely serving as conceptual symbols. At the same time, it was realized that theory cannot be equated with reality, and the term 'concept' was replaced on occasion by the term 'model', which places greater stress on the construction of a network of relations between concepts. It should now be possible to demonstrate the underlying analogy between the models of the different sciences. Models may be either static or dynamic, cyclic or cumulative; they may consist of functional or conjectural relations or show how the part fits into the whole. What difference is there between 'simulation', the value of which has been emphasized by operational research, and the practice of making small-scale models? It might almost be said that operational research came into being when the first grave doubts arose over the meaning and general applicability of the scientific method.

2. The very growth of technology based on twentieth-century scientific discoveries has made it imperative to apply scientific methods to the field of management. Production units are daily increasing in size and complexity; organizational problems are becoming more and more intricate; and important decisions now involve a growing number of variables, which are difficult to control. Whereas, a few decades ago, factory supervision was a simple matter, often concerned solely with the quality of goods, technological progress has made it both possible and necessary to provide accurate measurements of operations and keep a continuous record of their progress. Every industrial concern has permanently at its disposal a mass of detailed statistical information regarding its output, sales, stocks, machine repairs, etc., and is in a position to initiate new schemes to improve its management. Facts and figures are available for increasing profits by several per cent more than could be achieved by relying only on intuition and experience. Costly though it may be, the research entailed becomes an economic proposition where the sums involved (as in large production units) are considerable and where the rather rigid organization of the units (if large) implies the establishment of production standards for fairly long periods. The type of engineer who begins the morning by allocating the day's work in the best possible way is dying out. Science calls for scientific methods. The coexistence of technological practices and that amalgam of traditional formulas and intuition which prevails in the management of industrial concerns, government departments and the like is only possible in the areas adjacent to a borderline forever changing.

3. The effect of these purely technical factors is accentuated by the crisis of Western civilization. The criticism levelled at capitalism has undermined the confidence of the present generation in the efficacy of an economic

system in which decisions are decentralized. We are becoming more and more intent on controlling economic phenomena. Governments make it their aim to prevent fluctuations in general conditions, ensure balanced economic growth and see that correct choices are made in the allocation of resources.

Again, there is the desire to influence demographic phenomena by trying to raise or lower the birth-rate as the case may be; while the psychologists, for their part, try to devise methods of giving individuals better guidance or preparation for life. And so, in all fields, the present-day world is in quest of rational patterns of behaviour. Intellectual leaders are exercised by the problem of how to run society, and the whole subject is a very anxious one. Conscious as we are that past civilizations lived only for a limited span, our aspiration is to dominate the course of history, and so we are constantly scrutinizing other civilizations as reflected in their religious and administrative institutions, their ethics and their art, in search of an answer to our own problems. And it is paradoxical, in this connexion, that operational research has been developed by the same society that gave birth to sociological criticism and to the great reconstructions of world history by Toynbee, Spengler and so many others.

4. From the social point of view, the development of modern management techniques is also bound up with the growth of the social stratum (the term 'class' would be straining the facts) consisting of those people whom Burnham describes as managers; they are for the most part—in France at any rate—the senior officials or engineers who control the big administrative or industrial units. In the nineteenth century, a predominant role was played in small- and even large-scale industry in France by the *patron* who, after completing his secondary schooling, was trained by his father in the business he would one day run. The main task of engineers at that time, therefore, was to formulate manufacturing processes. The growth of joint stock companies, the concentration of industry and the desire for power gradually induced the engineering graduates of the French professional high schools to switch from purely technical to managerial posts. As they have all gone through much the same training, they now form a very homogeneous group with little interest in political power but playing an increasingly decisive part in economic expansion.

The scientific knowledge they have acquired before or during their career makes them very favourable, relatively speaking, to the principles of operational research. At the same time the many opportunities which present-day legislation affords senior civil servants to play a part in economic life are drawing them into industry and encouraging them to overhaul traditional methods of management. In this connexion, we need only mention the influence exercised by the Commissariat Général du Plan.

5. It must also be admitted that in certain cases the development of operational research is accompanied by that loss of initiative and zest for action which is an unfortunate feature of our Western societies. In France much of the time of our administrators is taken up with undoing the work of their French or foreign colleagues, or in out-manoeuvring particular social groups. The system of commissions and sub-commissions, coupled with the mental agility of the graduates of the French professional high schools only adds to the intensity of the endless competition for influence. We are not so fond of taking risks as we used to be, and before any decision is taken it is carefully dissected and examined from every angle. Operational research is useful in this respect because it gives those who have to make decisions the support and guarantee they need, but on no account should it become an instrument in the hands of those who are merely trying to use science to defend their own interests or place further obstructions in the way of decision making, under the pretext of 'studying' a particular question. In support of the point argued above is the fact that—so far as we can judge from the scrappy information available to us—the Union of Soviet Socialist Republics, which has a completely planned economy, lags behind in matters relating to applied economics, operational research and theories of decision making.

The above survey is, of course, a mere summary of the facts, which need to be subjected to a more searching analysis. It does, however, give a general idea of how operational research ties up with other developments of the modern world.

It explains to us how we, following the example of the Egyptians who in all probability developed two-dimensional mensuration under the pressure of agricultural requirements, are in turn constructing a mathematical system that will meet our needs—a novel one that is concerned with programming and probability factors. And we are quite justified in speaking of the mathematics of programming, for our aim in very many cases is to find the combination of decisions (and hence the values of certain variables) that will enable us to derive the maximum profit from a particular operation, within the limitations of our possibilities (i.e., limits imposed by the pressures on the variables). What makes this problem even more complicated is the fact that we often have to take a succession of decisions depending on the time factor. In many cases, also, variables can be given certain values only (for instance, the size of a thermal power plant is bound to be an arbitrary choice, for the present state of technology dictates that power plants must consist of standard sets). This gives rise to combinative mathematics—a branch of study which is still in its infancy. At the opposite end of the pole comes probability theory, covering research into rational behaviour in the presence of probability factors occurring with a given

frequency. Instances are problems of supplies, queueing, regulation of production and stock-piling. This shows how operational research can impinge even on mathematics.

Approaching the question in more general terms let us now consider the potential impact of operational research on the development of society and contemporary thought and try to forecast the way it will affect: technical manufacturing processes, the organization of individual undertakings, administrative organization, scientific thinking.

Operational research will facilitate the transformation of manufacturing processes, and in that respect its development will be closely linked with that of the automatic processing of information, on the one hand, and of automation proper, on the other.

There is a tendency among laymen at present to confuse operational research and automatic processing of information although as far as operational research is concerned electronic computers are only one of the means of processing the numerical data which it works on: many of the operational research problems can be solved numerically by hand or with the aid of office machines. Electronic computers are not yet so easy to use, and that form of mental laziness which consists in giving the machine inadequately formulated problems to solve needs to be fought against. But a change in the relations between operational research and the automatic processing of information is bound to take place for the following reasons:

1. The latter will increase the investigative means at the former's disposal by permitting the continuous recording of important data.
2. Operational research workers, with their added experience, will be able to co-operate more effectively with scientific computation experts.
3. Computing machines will become progressively easier to work as time goes on. The idea has already been mooted of formulating programmes permitting the use of a logical or mathematical language which comes as close as possible to ordinary language. The efforts in that direction have given rise to interpretative programmes and auto-programmes. The interpretative programmes (e.g., Flair and Flex for the IBM 650) are recorded on the machine whenever it is a case of excuting a programme set down in logical language, and the instructions are then interpreted as and when they occur. The purpose of the auto-programmes (AP2 for the BULL AET, Fortran for the 704, Paso for the 650) on the other hand is to produce the machine-language version of a programme which is fairly easy to construct and at the same time make a certain saving in computation time. This procedure results in a very good utilization coefficient for the machine despite the apparent loss of time represented by the phase during which the final programme has to be established from its 'auto-programmed' version.

4. Computers will enable us to solve problems beyond our present practical capacity. The number of memories in a computer and the speed of computing are very important factors as far as combinative problems of all kinds are concerned. In point of fact, there is a general absence of mathematical methods applicable to such problems whereby we could determine the optimum solution by successive approximations, and we have often no option but to review all the possible solutions and determine which one gives the highest value to the function to be maximized. It is true that this review is conducted in an intelligent manner and may result in cutting computation time to a tenth or even a hundredth, depending on how it is done, but the fact remains that the number of solutions to be reviewed is extremely high. The perfecting of computers means a considerable increase in this connexion in the progress of operational research.
5. At the same time, operational research studies will themselves be an aid in determining optimum systems for information processing. They will be useful in establishing forecasts of the evolution in time of the volume of information to be processed, and enable breakdown costs and the economic margins for a variety of technical solutions to be determined.

It is also easy to forecast how operational research and automation proper will affect each other. The latter is simply inconceivable in the absence of studies on such subjects as the number of safety devices to be installed, the response time of servo-mechanisms, the arrangement of factories, the size of production units, and so on. The case of oil refineries—or, to take a broader category of distillation plants—sufficiently proves this point. Moreover, the operational research problems raised by automated plants will be better formulated, since the numerical data will be more precise, the characteristic values more constant and the relations between them more stable, thus facilitating the establishment of mathematical models. The increased size of production units, again, will be a factor enhancing the profitability of operational research studies, for whereas the profit accruing from a study is more or less proportionate to the size of the unit, its cost increases less rapidly than the latter.

The effect of operational research and related techniques on the organizational structure of undertakings will be no less profound. The chain of relationships in the old type of undertaking was mainly hierarchical, with information and instructions passing from top to bottom, and the directors were men qualified to handle problems by their combination of administrative and technical ability. The diversification of techniques, together with the new thinking of which operational research forms part, have been contributory factors in the advent, succeeded by the steady development, of a functional chain of relationships conveying information and advice of an essentially technical nature. The present tendency is for the modern director

—the executive, in the Anglo-Saxon countries—to have at his command a general staff of functional assistants whose importance increases the higher the hierarchical level. These staff groups are in constant touch with each other, and the effect is to render the hierarchies somewhat looser and less rigid. At the same time the development of inter-communication promotes a collective approach to the work. The short-circuiting of individual steps in the hierarchical ladder, at one time heavily frowned upon, is no longer taken so seriously, and there are many problems today which are now studied by joint bodies consisting of representatives of the hierarchy and of the various functional services. The future development of operational research will be even more strongly marked by an increase in the size of these functional general staffs, whether they take the form of internal services or—for particular problems—of outside consultants. The development of consultant firms is significant in this respect. Until a few years ago there was a clear-cut distinction between engineering research firms—major undertakings equipped in many cases with laboratories and employing large staffs of specialists in various fields—and labour organization consultants' practices headed by a strong personality assisted by a small body of engineers always liable to launch out on their own. In those days, the consulting engineer was essentially a man whose individual qualities were what counted. The advent of operational research and the development of modern management techniques, on the other hand, will probably give rise to consultants' practices which have a much closer resemblance to engineering research firms. Their staffs will include a wide range of specialists, and their efficiency will depend on the volume of resources at their command and the level of competence of their teams as a whole.

It is probable that relations between operational research and labour organizations will also become closer, for it can legitimately be expected that the next twenty years will see the birth of administrative science in the true sense of the word, and based on experimental studies covering the transmission of information in organizations, the implications of individual flow-charts and the various aspects of centralization and decentralization. Operational research will be able at that stage to give real service in determining the most appropriate administrative structures.

But it would be dangerous to deduce from the foregoing that the importance of the director will diminish. The object of research work is to help him to reach a decision, and its conclusions are not binding on him: it is for him to make the decisions in the light of the arithmetically undefinable factors inherent in the problem. Herein lies the element of risk which is the essence of life itself. There will thus be an increasing differentiation between the man who makes the study and the man who makes the decisions—a differentiation conditioned by their personal aptitudes or dissimilarity in psychological make-up. We cannot have good operational

research in the absence of executives, and one of the latters' most difficult tasks will be to achieve a proper balance between studies and decisions, for an excess of studies may destroy the spirit of initiative and the ability to reach quick decisions, while over-hastiness in making decisions may lead to very costly economic blunders. The fact that the spirit of initiative is not always so marked as it was in the nineteenth century will make it all the more difficult to strike that balance.

Operational research may have certain specific effects on administration apart from those just described. By enlarging the possibilities of making rational decisions in respect of integrated industrial units, it will whet the taste for planning—whether we like it or not—and make it easier for the State to take control of the economy. Leading officials in all countries are deeply concerned at present at the poverty of the means at their disposal for analysing the tremendous repercussions that public investments are having on the development of their national economies. Many of the economists have been trying for the past decade to transfer economic cost calculation from the factory level to the community level. Where, a small amount of gas is supplied to a given area, for example, the price is high and the only purchasers are those consumers who find its use profitable. If the supply is increased, the price falls and more and more sections of consumers are reached who are prepared to pay the correspondingly lower prices.

It is only the marginal consumers who derive no more than a minimum benefit from purchasing the gas: the first batch of consumers, who had been prepared to pay a higher price, find its purchase far from unprofitable. A start is also being made at present on the study of urban development costs in the hope of obtaining a more rational conception in a few years' time of the problems of area development, taking account of the differences in incomes that would result from the establishment of undertakings in different localities and the differences in cost in developing those localities. All these studies have the effect of bringing out the divergencies between public and private interest which are increasingly leading the State—rightly or wrongly—to take action in the matter. At the same time, however, operational research can help to render State control less blind by providing the powers that be with better information about the consequences of State action, and it can also help administrators to develop a regular philosophy of State action which would make administrative decision less arbitrary and give officials a keener awareness of the public interest. Operational research specialists should beware, in this connexion, of allowing their studies to become two-edged weapons in the interminable discussions of experts and the struggles for influence. They should refuse to conduct studies in cases where the numerical data is selected in such a way as to bias the result in a certain predetermined direction, and where the purpose

of the study is to help to justify a pre-established political line in the eyes of outside parties. The results of operational research studies are often so closely linked with the data, in fact, that only the specialist can detect the slight 'twist' which causes the findings to be modified. Nor does operational research stand to gain if it has to rely for its development on a refusal to accept responsibility.

Lastly, the future relations that will develop between operational research and scientific thinking can be easily descried:

1. Operational research will give rise to a tremendous development in new branches of mathematics, and especially of combinative mathematics and probability theory. Typical examples are near at hand. It has already given rise during the past few years to the theories of linear programmes (including linear programmes in intagers in relation to determinants) as well as of dynamic programmes, and to the theory of graphs, the possibilities of which are only now beginning to become apparent. In the field of probability theory, meanwhile, progress has been made in research on conjectural processes, the functions of statistical decisions and the laws of probability.
2. Operational research will also be of help in the formulation of effective methods of numerical calculation.
3. It will act as a nursery for developing those of the pure sciences which stand in the same relationship to it as physics and chemistry do to chemical engineering; namely, economic science, administrative science, political science, sociology and psychology (in some respects), and military science. To mention only one or two points as far as economic science is concerned, it can be said that substantial progress has been made during the past decade in its application to industrial management but that much remains to be done—as tasks for the future—in studying economic interrelations, urban development costs, regional and national development problems, and guidance in group decision-making. The work in all these fields will be done in close symbiosis with operational research, which means that educators and research experts will be far more intimately linked with national economic life than in the past.

But it would be wrong to imagine that this development will be altogether plain sailing. Operational research will have to face difficulties and will meet with opposition and setbacks. It will have to begin, in fact, by learning humility. Unlike many of the scientific disciplines, it was born in a spirit of pride, and many of those who are not expert in the subject are still asking whether it can solve all problems. Time itself will reduce everything to its due proportions, but at the cost of temporary disappointments. The good work will be separated from the bad by a process of decantation; and there will be periods of stagnation, like the one that now seems to have opened following the amazing creative effort of the past few years.

Some of the sectors now included in operational research will become so familiar that they will form part of every engineer's normal equipment. The rest of the field will probably be broken down into narrower but still related specialities, and this again will be a source of sometimes fruitful and sometimes barren discussion. The term 'operational research' may even disappear from current language and the work itself be absorbed by various branches of technology closely allied with some of the scientific disciplines.

The issue, nevertheless, is not in doubt, for operational research is not an isolated or accidental phenomenon but the manifestation of a state of mind stemming from modern group psychology. The Western European countries, which have played an always creditable part in the development of operational research, will make a decisive contribution towards its future progress, for our engineers, though they may lack interest in technical details as such, often combine that characteristic with a sound general education and a good knowledge of mathematics.

Contact with operational research may even, in fact, be an excellent school of training for them. It teaches them to be painstaking in elaborating numerical data; to seek out the valid and relevant hypotheses in every problem; to keep their minds always alert; and to strike a fruitful balance between a pragmatism completely dependent on reality and an urge to abstract thinking which loses sight of the facts. The prospects then, are fairly favourable; and it now remains for our generation to draw the necessary conclusions as far as theoretical research, practical application and instruction alike are concerned.

CURRENT PROBLEMS AND RECENT NEWS

Science in Modern India

by

A. RANGANATHAN

A. Ranganathan was educated at a Scottish mission school, at an American private school and then at Madras University, where he specialized in science (physical sciences). He later studied economics. He has devoted himself to scientific writing and has published several articles such as 'Science and freedom' and 'Science teaching in Indian schools' in various periodicals.

The renaissance of science in modern India began as a result of the British influence on Indian society. Although it was India which gave the world the concept of zero in mathematics, the early knowledge of the properties of elements and their compounds, and the observatories for the study of astronomy, it is no exaggeration to state that the scientific spirit of India was submerged in a medieval backwater. Indeed, Sir P. C. Ray stated that her soil was rendered 'unfit for the birth of a Boyle, a Descartes or a Newton and her very name was all but expunged from the map of the scientific world for a time'.[1] In trying to analyse the reasons for the decline of the scientific spirit in India, Sir P. C. Ray observed: 'Science in India proceeded in a wrong way with the pursuit of alchemy and occultism, and, in consequence, came to stagnation and decay in the late Middle Ages. For the same mechanism, it may reasonably be assumed, possibly works in the evolution of the human mind, revealed by its civilization and culture, as in the organic evolution, proceeding through the combination of adaptation, natural selection and mutation. The last named gives a new and fruitful turn to the course of evolution when it runs into a blind alley leading either to an extinction or arrest. In the case of mental evolution, there is, however, one difference: while in organic evolution the organism itself has no control over the mechanism, acting merely as an instrument, in the case of mental evolution the mind takes an active part in the process, either co-operating with, or acting in antagonism to, the evolutionary urge in force. Hence, the phenomenon of mutation assumes a greater significance in this case. In the mental sphere these mutants arise from the birth of geniuses, saints and seers, who contribute to the progress of human civilization. The condition

1. P. C. Ray (ed.), *History of Chemistry in Ancient and Medieval India*, published by the Indian Chemical Society, 1956, pp. 241-2.

of science in Europe also was no better in this period (Middle Ages) than that prevailing in India. But the birth of Copernicus, Galileo, Newton, Boyle, Lavoisier and Dalton gave an entirely new turn to its course and their ideas and thoughts imparted a fresh impetus. These could not, however penetrate India until the advent and consolidation of British rule towards the middle of the nineteenth century. Another writer[1] attributes the intellectual stagnation of India after the close of the twelfth century, among several factors, to the decline of Buddhism under whose aegis science and medicine had flourished in the universities and hospitals attached to the Buddhist monasteries at Pataliputra, Taxila, Saranath, Nalanda, Vikramsila and Udantapura between the fifth and the eleventh century A.D. The unsettled state of affairs and lack of security in the country as a result of repeated foreign invasions and frequent changes in government were other factors which contributed to the decline of science and medicine in the period from A.D. 1200 to 1900.

Harvey, the discoverer of the circulation of the blood, is said to have remarked that Bacon 'wrote of science like a Lord Chancellor'. Similarly, one is tempted to remark that Raja Ram Mohan Roy (1772-1833), who is known as the father of modern India, wrote of science like a prophet. In 1823 the Government of India had appointed a committee to report on the best means of encouraging education in India. And on the recommendation of that committee a college was established for the teaching of Sanskrit. In a historic letter, written in 1823 to Lord Amherst, the then Governor-General of India, Raja Ram Mohan Roy protested against the government's decision to establish the traditional pattern of education and wanted the Government of India to 'employ European gentlemen of talent and education to instruct the natives of India in mathematics, natural philosophy, chemistry, anatomy and other useful sciences, which the natives of Europe have carried to a degree of perfection that has raised them above the inhabitants of other parts of the world'. And while drawing the attention of Lord Amherst to the state of science and literature in Europe before the time of Lord Bacon and the progress of knowledge made since he wrote, Raja Ram Mohan Roy added: 'If it had been intended to keep the British nation in ignorance of real knowledge, the Baconian philosophy would not have been allowed to displace the system of the schoolmen which was the best calculated to perpetuate ignorance. In the same manner the Sanskrit system of education would be the best calculated to keep this country in darkness, if such had been the policy of the British legislature. But as the improvement of the native population is the object of the government, it will consequently promote a more liberal and enlightened system of instruction, embracing mathematics, natural philosophy, chemistry,

1. M. R. Dhar in: *The Cultural Heritage of India*, Vol. III, Calcutta 1937, p. 453.

anatomy, with other useful sciences, which may be accomplished with the sums proposed by employing a few gentlemen of talent and learning educated in Europe and providing a college furnished with necessary books, instruments and other apparatus.'

The introduction of Western learning in India can be traced to the pioneer efforts of David Hare and Raja Ram Mohan Roy, who established a *Vidyalaya* (home of learning) at Calcutta in 1816 for the 'tuition of sons of respectable Hindu parents in the English and Indian languages and in European and Asiatic science and literature'; its name was later changed to Hindu College and in 1855 to Presidency College since when it has achieved a great reputation as the leading institution of Bengal. And soon the Christian missionaries established a missionary college at Serampore in 1818, the Wilson School at Bombay in 1834 and the Madras Christian College at Madras in 1837. During this period, the aim of the government was to impart 'through the medium of English, the literary and scientific information necessary for a liberal education'. The idea was that the knowledge which was confined to a select few in the beginning would soon penetrate to the outer community 'through the channel of a new vernacular literature'. This was known as the 'filtration theory'. But in the wake of Sir Charles Wood's dispatch of 1854 'the old idea that education imparted to the higher classes would filter down to the lower classes was discarded', and the government was required to create 'a properly articulated scheme of education, from the primary school to the university'. This dispatch outlined a programme for the foundation of a university system in India as a result of which the Madras, Bombay and Calcutta universities were established in 1857. Soon other universities were established in different parts of India. The founding of the universities in India was a further tribute to the far-sighted vision of Raja Ram Mohan Roy.

The history of science in modern India can be said to begin with the foundation of the Asiatick Society (later known as the Asiatic Society of Bengal and now known as the Royal Asiatic Society of Bengal) in 1784 by Sir William Jones. Scientific progress was maintained through three main agencies: societies such as the Royal Asiatic Society of Bengal, the great official scientific services, and research work of individual scientists in the universities.

The objects of the Asiatick Society were explained thus by Sir William Jones: 'If now it be asked, what are the intended objects of our inquiries within these spacious limits, we answer, Man and Nature; whatever is performed by the one, or produced by the other.' The society provided 'a commodious house for scholars, the making of a library, of a collection of ancient coins and medals, of a collection of pictures and busts and the formation of archaeological, ethnological, geological and zoological collections or museums'. The journal of the society published a number of

research papers in the various sciences—botany, physics, chemistry, geology and mathematics—and also a number of papers on differential equations by Ashutosh Mukopadhay, who later distinguished himself as Sir Ashutosh Mookerji; a paper on the polarization of electric rays by double refracting crystals by J. C. Bose; and several papers on mercury salts by P. C. Ray. Again, it was Sir William Jones of the Asiatick Society who identified the Indian ruler Chandragupta with the 'Sandracottos' of Greek historians and 'Palibothra' with Pataliputra; this marked the beginning of 'Indian historical writing unmixed with fable'. Indeed, these discoveries by Sir William Jones helped in recovering the lost pages of ancient Indian civilization and laid the foundations for a scientific study of Indian history.

Branches of the Royal Asiatic Society of Great Britain and Ireland were established at Bombay and Madras. In Madras, a society called the Madras Literary Society and Auxiliary of the Royal Asiatic Society began work in 1833 and published a journal entitled first the *Journal of Literature and Science* and later the *Madras Journal of Literature and Science* which continued till 1894. Two other societies which deserve mention are the Agricultural Society of India founded in Calcutta in 1820, the name of which was changed to Agricultural and Horticultural Society of India (later it became known as the Agri-Horticultural Society of India) and the Bombay Natural History Society founded in 1883.

In his presidential address to the Silver Jubilee Session of the Indian Science Congress in 1938, Lord Rutherford [1] referred to the 'pioneer work of outstanding scientific importance' done by the services such as the Survey of India, the Geological Survey, the Botanical Survey, the Department of Meteorology and many others. Lord Rutherford also dealt in his address with the important work carried out by the Trigonometrical Survey which has a most distinguished record. He said: 'The splendid series of geodetic measurements along an arc from Cape Comorin to the Himalayas made by Everest was of outstanding importance and his name is for ever associated with the highest peak in the world. As a result of this survey, the deflections of a plumb line due to the gravitational attraction of the Himalaya range, were determined at different points. A careful comparison of the results of observation with calculation, largely due to the work of Archdeacon Pratt of Calcutta, and later of Sir Sydney Burrard disclosed marked discrepancies, the effect of the mountain mass at a distance being much less than was expected. Attempts to explain these and other anomalies ultimately led to the formulation of a new and important theory of mountain formation known as the principle of isostasy. On this hypothesis, the excess pressure due to a mountain mass is compensated for by a deficiency of matter below its base. This conclusion, which is in accord with extensive gravitational as

1. *Proceedings of the Twenty-fifth Indian Science Congress, Calcutta, 1938*, published by the Royal Asiatic Society of Bengal, Calcutta, pp. 8-9.

well as geodetic measurements in India, is believed to be of general application to mountain formation throughout the world.'

This survey, known originally in 1800, as the Trigonometrical Survey of Peninsular India was soon extended as the Great Trigonometrical Survey of India in 1818, and was consolidated with the Topographical and Revenue Surveys in 1878 as the Survey of India. The Geological Survey of India, which is noted for its survey of the mineral resources of India, was established in 1851. The Tata Iron and Steel Works owes much to the scientific insight of Sir Thomas Holland, one of the earliest directors of the Geological Survey. Botanical studies in India began with the foundation of the Calcutta Botanical Gardens (later known as the Royal Botanical Gardens) in 1788. The Botanical Survey of India was founded in 1889. Zoological research in India began with the appointment of Edward Blyth as the Curator of the Museum of the Asiatic Society in 1841 and in 1916 the Zoological and Anthropological Sections of the Indian Museum were merged to become the Zoological Survey of India. The Department of Meteorology conducted investigations into the conditions of upper air by means of small balloons. One of the directors of the Department of Meteorology was Sir Gilbert Walker, who in addition to introducing statistical methods of long-range forecasting into meteorology has made outstanding contributions to our knowledge of the south-west monsoon. In forestry, much useful work has been conducted at the Dehra Dun research laboratory, which according to Lord Rutherford was 'probably the finest research laboratory of its kind in the world'. Finally, the Indian Medical Service had made rapid strides in increasing our knowledge of the tropical diseases—the great work of Sir Ronald Ross on the mosquito transmission of malaria and the pioneer work of Leonard Rogers on cholera and leprosy are well known.

At the end of the last century, individual scientists in the science departments of the universities began making important contributions to different branches of science. Modern India's scientific research began with Professor J. C. Bose's work on electric waves. At the beginning of his career, Bose was engaged in a number of scientific hobbies including sound recording, and was especially interested in Hertz's experiments with electromagnetic waves; these led him on to a deeper investigation of the properties of electric waves. This, in turn, helped him to study the similarity in behaviour, under the action of electric waves, of a class of substances used for detecting such waves and living tissues, as a preliminary to the study of the responses in living and non-living matter. These studies inspired him to investigate the physiological properties of plant tissues and to show examples of the similarity of their behaviour and that of animal tissues. The detector of electric waves in his apparatus was called a 'coherer', whose resistance was reversibly reduced under the impact of electric radiation, which could be detected by a deflection of the galvanometer connected with

the coherer. Bose did not draw any line of demarcation between physical and physiological phenomena. He devised a number of instruments to record the response of plants. The first one, which was completed in 1911, was the resonant recorder which automatically recorded the velocity of nervous impulse in the Mimosa petiole and could estimate time values as short as a thousandth of a second. To measure linear growth movements in plants, he constructed, in 1917, his compound lever crescograph which could show a magnification of 5,000 times. And then came the magnetic crescograph which magnified 1 million times, the 'bubbler' or photosynthetic recorder, in 1922, for measuring the rate of photosynthesis in plants, and the diametric contraction apparatus which can demonstrate diametric expansion and contraction in plants under the effects of heat or cold, poison or stimulants. Ever since Bose published his monograph on 'Responses in the living and the non-living', there has been tremendous excitement in the non-scientific world about the pantheistic nature of its scientific conclusions. 'Sir Jagadish Chandra Bose' wrote *The Times,* 'is a fine example of the fertile union between the immemorial mysticism of Indian philosophy and the experimental methods of Western science.' The pantheistic outlook of ancient Indian culture (whether consciously on unconsciously it is difficult to say) was woven into the texture of the scientific thought of Sir J. C. Bose.

Professor C. V. Raman began his investigations on the scattering of light in 1919 at Calcutta. During his voyages to and from Europe, Raman had made observations of the colour of the sea. Formerly, the blue colour of the sea was attributed to the reflection of blue sky light or to the presence of suspended matter. Professor Raman, who conducted laboratory experiments on the scattering of light by pure water, was able to conclude that the colour of the sea was due to the molecular scattering of light. This led him to make a systematic study of the depolarization of light scattered by various liquids. In 1921, Raman observed that when sunlight is used as the incident light, the depolarization of the light scattered transversely by distilled water increased markedly when a violet filter was placed in the path of the incident beam. At first, it was thought that the dependence of the depolarization of scattered light on wave-length of incident light was due to 'fluorescence'. However, by a stroke of genius Professor Raman saw that this phenomenon might be the optical analogue of the Compton effect and he proceeded to experiment in this direction. He used sunlight as the incident beam with two light filters, one blue-violet and the other green, the idea being that the green filter could cut off all the radiation transmitted by the blue-violet filter. The blue-violet filter was placed in the path of the incident beam and when the green filter was placed in the path of the scattered light, it was shown that all the scattered light could not be cut off, since a feeble green light was detected. It was clear that this green light was

polarized and different from scattered light as well as from fluorescent radiation; it was due to a new type of secondary radiation. The final step was taken by Professor Raman in February 1928, when he used the light of the mercury lamp as the incident beam and found in the spectrum of the light scattered by various substances new lines or bands which were not present in the incident beam of light. Raman could then announce his famous discovery that if monochromatic light was passed through a transparent liquid, the light scattered by the liquid contained not only light of that colour but also monochromatic light of some other colours. This great discovery, known as the Raman effect (predicted by Smekal in 1923), won international recognition for Professor Raman, including the award of the Nobel Prize for Physics in 1930. Although it is a great discovery in physics, it is also an effective tool in the study of the structural problems of chemistry. As Hibben remarked, the 'Raman effect began as the step-child of physics, but as time progressed, it became the adopted child of chemistry'.

Professor M. N. Saha, who was the first Indian scientist to realize the importance of astrophysics in India, had published his theories of thermal ionization and worked out the physical theory of stellar spectra. In his first paper 'On ionization in the solar chromosphere' (published in the *Philosophical Magazine,* London, 1920) Professor Saha deduced the celebrated 'ionization formula' and showed that the enhancement of the chromospheric spectrum was due to a lowering of pressure in the chromosphere. In his subsequent papers, Professor Saha postulated a general theory as to why lines of certain elements only are observed in the sun. He treated the ionization of an element as a chemical decomposition, the decomposed constituents being an electron and the remainder of the atom. The most weakly bound electron is loosened from the atomic structure as soon as the temperature of the element rises. And at a higher temperature, the next weakest bound electron is loosened and so on. Therefore, under conditions prevailing in the sun's atmosphere, some of the atoms may not be found in the normal state at all. Saha's theory gave a clear explanation for the absence of the spectral lines of some elements in the Fraunhofer spectrum and his prediction that some of the missing elements would be found by examining the spectra of sunspots proved correct. Professor Saha's work has helped to estimate the surface temperature of stars. His work has had a tremendous impact on the future growth of astrophysics. As Professor Rosseland says: 'The impetus given to astrophysics by Saha's work can scarcely be overestimated, as nearly all later progress in this field has been influenced by it and much of the subsequent work has the character of refinements of Saha's theory. And, in the *Encyclopaedia Britannica* (14th edition), Sir Arthur Eddington characterized Saha's theory as 'one of the ten outstanding discoveries in astronomy and astrophysics since the discovery of the telescope, in 1608, by Galileo'. Professor Saha's tradition has been continued

by Dr. S. Chandrasekhar, who is now a distinguished Professor of Theoretical Astrophysics at the Yerkes Observatory, Chicago. Professor Chandrasekhar's scientific work has ranged from stellar interiors and atmospheres to stellar motions and the dynamic properties of clusters and galaxies. Dr. Chandrasekhar has also developed a new statistical theory of stellar rotations and contributed towards the understanding of the theory of turbulence. He has written three important books—*An Introduction to the Study of Stellar Structure* (University of Chicago Press, 1939), *Principles of Stellar Dynamics* (University of Chicago Press, 1943) and *Radiative Transfer* (Oxford, Clarendon Press, 1950).

Dr. Chandrasekhar's most important recent work has been in tracing the evolution of stars. In Chandrasekhar's own words : 'If our knowledge of the structure, the composition and the source of energy of the stars were complete, we should, in principle, be able to follow the course of evolution of a star on the assumption that evolution proceeds along a sequence of equilibrium configurations. It is possible that such an investigation will reveal that secular evolution of the type contemplated is impossible at certain stages; if that is the case, it is highly important that we establish it, since discontinuities in stellar evolution are suggested by a variety of stellar phenomena, including those of the novae, the super novae and the SS Cygni stars.' What would be the fate of a star 'once the source of nuclear energy stops through the exhaustion of the available supply of hydrogen in the central regions?'. Chandrasekhar shows that 'the analogy of a star to a log of wood which burns itself out completely and leaves only ashes—or helium in the stellar context' is not a good one, and concludes that possibly 'the star has recourse to contracting in the manner imagined by Helmholtz and Kelvin, releasing gravitational energy'. He says: 'The fact that completely degenerate matter in equilibrium under its own gravitation is best likened to a gigantic molecule in its ground state (R. H. Fowler) makes it attractive to suggest that white dwarfs represent the final states of stars. The fact that known white dwarfs do not contain any hydrogen lends support to this view. But the existence of the limiting mass makes it attractive only for stars whose masses are less than 1.4 times that of the sun.' What of the fate of stars with masses greater than Chandrasekhar's limit (the famous 1.4 criterion known as Chandrasekhar's limit)? Professor Fred Hoyle gives a lucid account in his *Frontiers of Astronomy*. According to him, 'it follows that the fate of stars with masses greater than Chandrasekhar's limit is certainly most curious, whichever alternative they elect to follow. One possibility is that they shrink indefinitely, the other that a fantastic catastrophe occurs. Which? Our conclusion . . . will be in favour of a catastrophe—or rather of two catastrophes, first a catastrophic collapse, then catastrophic explosion. The explosion turns out to solve the star's problem, for it removes so much material that the mass is brought below Chan-

drasekhar's limit. When this happens degeneracy can take control of the pressure balance, the star can cool off and evolution can proceed tranquilly to the white-dwarf state'.[1]

Professor S. N. Bose worked out a new statistics of the ultimate 'light particles' or 'photons' without invoking the aid of material particles (resonators). He has able to show that the number of photons within a definite range of frequency contained in a unit of volume at a definite temperature is uniquely determined, and calculated the correct distribution of the density of radiation. Bose's work, which was confined to the statistics of an assembly of photons in a six-dimensional phase, was later extended by Einstein to an assembly of material particles. It is well known that this method in quantum statistics, which became known as the Bose-Einstein statistics, has inspired Fermi and Dirac to formulate their statistical application to most elementary material particles known as the Fermi-Dirac statistics.

The greatest figure in the world of Indian mathematics was undoubtedly Srinivasa Ramanujan. Born of poor parents and subjected to untold hardships in his early life, he developed into one of the most outstanding mathematicians of his age, although his career of unusual promise was cut short by his death when he was hardly 33. He had no university education and joined the Madras Port Trust as a clerk, soon after he had left school. Professor G. H. Hardy got Ramanujan a scholarship, which enabled him to go to Trinity College, Cambridge. Some account of the working of Ramanujan's mind can be had from the following admirable description by Professor Hardy: 'There was one great puzzle. What was to be done in the way of teaching him modern mathematics? The limitations of his knowledge were as startling as its profundity. Here was a man who could work out modular equations, and theorems of complex multiplication, to orders unheard of, whose mastery of continued fractions was, on the formal side at any rate, beyond that of any mathematician in the world, who had found for himself the functional equation of the Zeta-function and the dominant terms of many of the most famous problems in the analytic theory of numbers; and he had never heard of a doubly periodic function or of Cauchy's theorem and had indeed but the vaguest idea of what a function of a complex variable was. His ideas as to what constituted a mathematical proof were of the most shadowy description. All his results, new or old, right or wrong, had been arrived at by a process of mingled argument, intuition and induction, of which he was entirely unable to give any coherent account. . . . It was his insight into algebraical formulas, transformations of infinite series and so forth, that was most amazing. On this side most certainly I have never met his equal and I can compare him only with

1. Fred Hoyle, *Frontiers of Astronomy*, Mentor edition, 1955, p. 185.

Euler or Jacobi. He worked far more than the majority of modern mathematicians, by induction from numerical examples; all of his congruence properties of partitions, for example, were discovered in this way. . . . One gift it has (Ramanujan's work) which no one can deny, profound and invincible originality. He would probably have been a greater mathematician if he had been caught and tamed a little in his youth; he would have discovered more that was new; and that, no doubt, of greater importance. On the other hand he would have been less of a Ramanujan and more of a European professor, and the loss might have been greater than the gain.'[1] His work is mainly concerned with the theory of numbers; his analysis of highly composite numbers reveals his insight into the algebra of inequality. His treatment of elliptic and modular functions is singularly original; and what are known as the Rogers-Ramanujan formulas constitute some of his most remarkable contributions to mathematics.

The historian of science in modern India cannot fail to note that Indian scientists have been particularly attracted to physics and mathematics rather than to chemistry and biology. Indeed, 10 out of 14 Indian Fellows of the Royal Society have been mathematicians and physicists. The pioneer of chemical research in India, however, was Sir P. C. Ray. In 1896, he had made his discovery of mercurous nitrite, a compound of unexpected stability. He had also isolated the amine-nitrites and investigated their physical and chemical properties. In addition to conducting valuable research work, he was responsible for establishing many industrial enterprises of which the Bengal Chemical and Pharmaceutical Works is the most famous.

Dr. Yellapragada Subba Row, who had spent most of his career at American Cyanamid's Lederle Laboratories, achieved world-wide fame through his research. He succeeded in synthesizing folic acid, which is useful in the treatment of the tropical disease, sprue. Dr. Subba Row was also associated with the discovery of aureomycin. He developed aminopterin and other folic acid derivatives which have proved effective against leukaemia and other forms of cancer.

The subject of nuclear fission and the idea of utilizing energy released during nuclear fission began to interest the late Professor Saha when Dr. Otto Hahn announced his historic discovery in 1939. With the help of grants, including a generous one from the Tatas, Calcutta University had assembled a cyclotron which was purchased from Lawrence's Laboratory in California. Indeed, as early as 1935, Dr. H. J. Bhabha carried out important work on the passage through matter of charged particles with a velocity approximately equal to that of light and made a detailed investigation into the creation of electron pairs by fast charged particles. And in an important paper published in the *Proceedings of the Royal Society* in 1937, Bhabha

1. *Collected Papers of Srinivasa Ramanujan*, edited by C. H. Hardy and others, published by the Cambridge University Press, 1927, p. xxx, xxxv and xxxvi.

and Heitler suggested a new mechanism of shower production. Assuming that the incident radiation consists of electrons, and calculating from relativistic quantum mechanics the number of secondary positive and negative electrons produced by a fast primary electron, it was shown that the primary electron in the field of nucleus emits a quantum which then creates a pair. Again the pair electrons emit a quantum which creates a pair, and so on. And in 1937, Professor Saha published a paper on the origin of mass in the neutron and the proton, giving a simple proof of the existence of free magnetic poles, first deduced by Professor Dirac.

India formally entered the atomic age with the establishment of the Tata Institute of Fundamental Research under the direction of Dr. H. J. Bhabha, F.R.S. Since atomic energy research was to be conducted exclusively by the Government of India, according to the Industrial Policy Resolution of 1948, an Atomic Energy Commission was set up in 1948 which led to the opening of the Department of Atomic Energy in 1954. Undoubtedly an important date in the history of atomic research in India is 4 August 1956, since India's first atomic reactor christened 'Apsara' then went into operation, symbolizing the beginning of the atomic age in India. This reactor was set up at Trombay, near Bombay, using fuel elements which are made of an alloy of enriched uranium and aluminium supplied by the United Kingdom Atomic Energy Authority. It is based on the fission process. As U-235 undergoes fission, it splits up into two nearly equal fission fragments and a few fast neutrons. The demineralized light water filling the space between the plates not only cools the plates, but is also a reflector of neutrons and acts as a moderator in the slowing down of fast neutrons, since fast neutrons are not unduly effective in causing fission. The reactor is put to several uses, that of testing materials for more advanced types of reactors and the preparation of radio-isotopes for application in medicine, agriculture and industry. And in the second reactor known as ZERLINA (Zero energy reactor for lattice investigations and new assemblies), heavy water will be used as moderator, natural uranium as fuel, and graphite as reflector; subsequently it is proposed to use deuterized hydrocarbons as moderators, mixed lattices of thorium and uranium as fuel, and heavy water as reflector. This reactor will contribute to the study and design of new reactor systems. The third reactor is the famous Canada-India Reactor (Canada's contribution under the Colombo Plan) in which the reactor is filled with long aluminium-sheathed rods of uranium. Heavy water supplied by the United States acts as the moderator. Also the heat from the reactor core is abated by a primary closed circuit of de-aerated demineralized light water which in turn is cooled by a secondary circuit of sea water from the harbour. This reactor is expected to go into operation by 1960 and will supply the country with radio-isotopes and provide facilities for scientific and engineering research.

India is fortunate in having monazite deposits in Bihar, Kerala and Madras. So far only the Kerala and Madras deposits have been exploited. In 1951, the Rare Earths Plant was set up at Alwaye, with the technical assistance provided by the Société des Produits Chimiques des Terres Rares of Paris. This monazite, which is obtained after being separated from the mineral sands collected on the beaches, is sent to the Rare Earths Plant at Alwaye for chemical treatment whereby a cake of thorium and uranium is obtained and dispatched to the Thorium Plant at Trombay (near Bombay City) for further treatment. The location of the plant at Alwaye, near Cochin harbour, makes transport both to Bombay and abroad easy.

Historically, the major instrument of India's economic transformation was foreign capital, especially British capital. In fact, the collapse of the traditional economy, an efficient civil service, the modern transport system, the making of roads, the construction of railways, the introduction of the telegraph system and modern methods of banking can be traced to the British influence in India. While the foundations of the modern Indian economy were laid by the British authorities, it was the House of Tatas which contributed to the industrial growth of the country. The industrial development of the country has not only had a powerful impact on India's economy but has also contributed to a relaxation (although the tempo is slow) of social rigidities and habits.

Although Sir Jamshedji Tata was not a scientist, he made a great contribution to the industrial and scientific progress of the country. Being a man of vision, he was associated with a chain of activities—the establishment of the Indian Institute of Science to provide facilities for scientific research; the famous Tata Iron and Steel Works which gave the initial impetus to the development of the country's economy; and the hydroelectric stations for the supply of cheap power and the conservation of the coal resources of the country. His activities served to emphasize the close relationship between industrial development and science in an underdeveloped country.

Speaking on 'The need for atomic energy in the underdeveloped countries, at the second International Conference on the Peaceful Uses of Atomic Energy held at Geneva in September 1958, Dr. Bhabha said:[1] Once one has come to the stage of basing a power programme on breeder power stations working on the thorium-uranium 233 cycle, the total capital investment in a million kilowatts of power would fall to Rs.1,400 million compared with Rs.1,600 million required for providing the same amount of thermal power based on coal.' Also, it is possible to argue that to a considerable extent the future of the food and population problem is linked with what may be termed the agricultural economics of atomic energy. Professor Ake Gustaffson's prediction, made at the Geneva Conference in

1. Evening lecture delivered by Dr. H. J. Bhabha, F.R.S. at the second International Conference on the Peaceful Uses of Atomic Energy held at Geneva in September 1958.

1955, concerning the new possibilities in plant breeding had opened up new vistas of the atomic revolution in agriculture. It is within the realm of probability that the electricity generated by atomic power stations would render possible the irrigation of hitherto neglected areas as well as the opening up of new land to agriculture. Paradoxical at it may appear at first sight, it is clear if we reflect on the problem of accelerating India's industrial growth that the use of atomic energy is of vital importance in an underdeveloped country such as India if the lag of centuries is to be made up.

Mr. Jawaharlal Nehru, Prime Minister of India, placed the following scientific policy resolution of the Government of India before the Indian Parliament on 12 March 1958. This resolution met with the approval of the Indian Parliament. In view of its importance (it has been hailed as a scientists' charter), we reproduce it in full:

The key to national prosperity, apart from the spirit of the people, lies in the modern age in the effective combination of three factors, technology, raw materials and capital, of which the first is perhaps the most important, since the creation and adoption of new scientific techniques, in fact, make up for a deficiency in natural resources and reduce the demands on capital. But technology can only grow out of the study of science and its applications.

The dominating feature of the contemporary world is the intense cultivation of science on a large scale and its application to meet a country's requirements. It is this which, for the first time in man's history, has given to the common man in countries advanced in science a standard of living and social and cultural amenities which were once confined to a very small privileged minority of the population. Science has led to the growth and diffusion of culture to an extent never possible before. It has not only radically altered man's material environment but, what is of still deeper significance, it has provided new tools of thought and has extended man's mental horizon. It has thus influenced even the basic values of life and given to civilization a new vitality and a new dynamism.

It is only through the scientific approach and method and the use of scientific knowledge that reasonable material and cultural amenities and services can be provided for every member of the community, and it is out of a recognition of this possibility that the idea of a Welfare State has grown. It is characteristic of the present world that the progress towards the practical realization of a Welfare State differs widely from country to country in direct relation to the extent of industrialization and the effort and resources applied in the pursuit of science.

The wealth and prosperity of a nation depend on the effective utilization of its human and material resources through industrialization. The use of human material for industrialization demands its education in science and training in technical skills. Industry opens up possibilities of greater fulfilment for the individual. India's enormous resources of man-power can only become an asset in the modern world when trained and educated.

Science and technology can make up for deficiencies in raw materials by providing substitutes, or, indeed, by providing skills which can be exported in return for raw materials. In industrializing a country, a heavy price has to be paid in importing science and technology in the form of plant and machinery, highly paid personnel and technical consultants. An early large-scale development of science and technology in the country could therefore greatly reduce the drain on capital during the early and critical stages of industrialization.

Science has developed at an ever-increasing pace since the beginning of the century, so that the gap between the advanced and backward countries has widened more and more. It is only by adopting the most vigorous measures and by putting our utmost

effort into the development of science that we can bridge the gap. It is an inherent obligation of a great country like India, with its traditions of scholarship and original thinking and its great cultural heritage, to participate fully in the march of science, which is probably mankind's greatest enterprise today.

The Government of India has accordingly decided that the aims of their scientific policy will be:

1. To foster, promote and sustain, by all appropriate means, the cultivation of science, and scientific research in all its aspects—pure, applied and educational.
2. To ensure an adequate supply, within the country, of research scientists of the highest quality and to recognize their work as an important component of the strength of the nation.
3. To encourage and initiate, with all the possible speed, programmes for the training of scientific and technical personnel, on a scale adequate to fulfil the country's needs in science and education, agriculture and industry and defence.
4. To ensure that the creative talent of men and women is encouraged and finds full scope in scientific activity.
5. To encourage individual initiative for the acquisition and dissemination of knowledge and for the discovery of new knowledge in an atmosphere of academic freedom.
6. In general, to secure for the people of the country all benefits that can accrue from the acquisition and application of scientific knowledge. The Government of India has decided to pursue and accomplish these aims by offering good conditions of service to scientists and according them an honoured position, by associating scientists with the formulation of policies, and by taking such other measures as may be deemed necessary from time to time.

But something more is needed than the offer of good conditions of service and an 'honoured position', although it is true that today the highest emoluments and status are enjoyed by persons employed in administrative and other sectors rather than by scientists. It is essential that scientists be appointed as head executives of the various State enterprises, so that they can be directly responsible to the ministers concerned. There is also a case for co-ordination of the personnel of the various scientific services of the country so as to build up a national scientific civil service.

The Government of India has established several higher institutions of research in pure science, for example the National Physical Laboratory and the National Chemical Laboratory, and central research institutes concerned with India's national resources, such as the Central Fuel Research Institute, the Central Electrochemical Research Institute, the Central Metallurgical Laboratory and the Central Food Technological Research Institute. In order to promote higher technological education, the government has also undertaken to establish four regional institutes of higher technology. The first of these, planned on the model of the Massachusetts Institute of Technology, was set up at Kharagpur in Bengal. A second has been set up at Bombay, a third will soon be opened at Madras, and the fourth will also be in operation in the near future. The loan of experts and the special programmes of technical assistance provided by the Specialized Agencies of the United Nations, Unesco, FAO and WHO, have of course been of great help to India in tackling the various scientific problems confronting her.

But it is as important to foster a scientific outlook in the country as it is to set up laboratories and research institutes. Commenting on the work of the Indian Science Congress, an industrial correspondent wrote in a leading daily: 'It was amazing that the last day's programme of the latest congress had to be curtailed and the session rather unceremoniously wound up because the vast majority of the delegates had left before the session concluded. . . . The Science Congress itself is involved in specific problems of the various branches of science and does not have sufficient time to think over the condition of science in general.' In his convocation address to the Delhi University, the Duke of Edinburgh emphasized the importance of the contribution being made by the British Association for the Advancement of Science in developing a scientific attitude among the people of Britain. He stressed the necessity of explaining the consequences of scientific research to the general public.

The proper teaching of science in schools is one of our most pressing problems. Even in an advanced country like England, a conference on science teaching in schools held in April 1958 under the auspices of the British Association drew attention to two major problems which faced the country—the supply of science teachers and the provision of laboratory accommodation and equipment for schools. Both these problems have even more serious implications for India. To take one example of the need for equipment, it would be of great benefit if some of our important schools were supplied with Geiger-Muller counters and various other pieces of apparatus. Using clocks with luminous dials as a source of radiation or bits of uranium ore, a demonstration could be given to the pupils of how the radiation will pass through their hands to be registered by the Geiger counter.

Although it might not be possible in the schools, given the lack of trained science teachers, arrangements should be made with universities in different parts of the country to hold common lecture demonstrations for all the schoolchildren in order to combat the tendency in some of our pupils to memorize science lessons. Indeed, as science is taught in our schools, it is often a mass of unrelated fact mechanically learned by the pupils. Even as early as 1899, Professor William Ramsay wrote: 'The colleges are wretched places as a rule . . . and the whole system is rigidly examinational like London University. They are reaping the fruits of it in a number of cramming shops, miscalled colleges.' The possibilities of using motion pictures, filmstrips and 'still' pictures (excellent pictures culled from first-rate journals) as aids in teaching science must also be fully examined. Nor are the history of science and scientific thought given a sufficiently important place in science education. The net result is that very few of our students have any grasp of the evolution of scientific ideas.

Most modern educationists believe that the scope of school education

should be broadened to include the study of magnetism and electricity, the weather, the stars and planets, sound, heat, light, chemistry; whereas the older type of curriculum placed the main emphasis on the study of plant and animal life.

The special importance of incorporating nuclear physics into the teaching of school science was also stressed at a pilot vacation course for organizers of refresher courses for science teachers, arranged by the European Economic Co-operation's office for scientific and technical personnel, held in August 1958, at Tutzing near Munich. A most valuable lesson to be learned by the pupils in their impressionable years is the importance of international co-operation. In studying the work of atomic scientists they will realize early that science knows no barriers and that scientists of different countries have co-operated in making some of the epoch-making discoveries of atomic physics. Such teaching would afford an excellent opportunity to link up two entirely different questions, the theory of the atom and the social consequences of atomic research, and would help to develop a scientific attitude towards general problems as well.

In discussing possible new orientations in our school programmes it is often suggested that there should be a greater emphasis on science. At the same time we are asked not to neglect human and literary values in our educational schemes. Indeed, it is well to realize that specialization need not begin at the high school stage. The word 'literature' does not merely refer to fiction and poetry. *The Mysterious Universe* by Sir James Jeans, *The Nature of the Universe* by Fred Hoyle, and *The Nature of the Physical World* by Sir Arthur Eddington are not only masterpieces of scientific exposition but are also good literature. To cite a modern example, Rachel Carson's *The Sea Around Us* is at once good prose and a good piece of scientific writing. The latest example is a series of Reith Lectures delivered by Professor Lovell on 'The individual and the universe'. The ultimate aim, although it is by no means easy to accomplish is to bring about what Dr. Oppenheimer calls 'the happy symbiosis of science and the general culture of the age. Recognized works in different fields such as astronomy, anthropology, biology and geology should be a part of the 'literary reading' of students in secondary schools.

The importance of continuing the use of English as a medium of instruction in our schools and colleges for several years to come was stressed by Professor D. M. Bose in his presidential address to the fortieth session of the Indian Science Congress: 'Scientists in this country view with some apprehension all premature attempts to replace English as a medium for the teaching of advanced sciences and for communication of results of scientific investigations by one of the Indian languages. There is enough scope for the popularization of science and the writing of science textbooks suited for schools. In Bengal, we have had a record of good science writing by men

like Akshoy Kumar Dutt, Ramendra Sundar Trivedi, Jagadish Chandra Bose, Prabulla Chandra Roy and Rabindranath Tagore. All of them were not scientists by profession, but they were all masters of the Bengali prose. Flexibility in the expression of fine shades of meaning and precision of expression are matters of slow growth in a language. Scientists in India should not be hampered in the communication of the results of their investigation by having to make additional efforts to express them in a language not fully equipped for such purposes.'[1] Quite apart from the fact that it has been a tradition in India to teach science through the medium of English since the modern universities were started, it is well to remember that the English langage is eminently suitable for the communication of observation, experiment and deduction.

But India has lost sight of the need for an intellectual background for the growth of the scientific attitude. There are many who, while enjoying the benefits of science, attack the material results of science as constituting a death blow to 'spiritual values'. They seldom realize that at the very moment when primitive man discovered fire and opened the first stage of civilization he had contributed to the birth of science. It is unfortunate that the intellectual ferment which occurred as a result of Raja Ram Mohan Roy's pioneering movement for intellectual emancipation has merely touched the fringe of Indian society.

The Indian philosophical approach to science is based on intuitionism. It is well known that the Upanishads, the fountain head of ancient Indian wisdom, have emphasized the superiority of what is called intuition, as distinguished from mere intellect. The effects of this tradition can still be detected in the writings of our modern Indian philosophers. Sri Aurobindo says: 'Our science itself is a construction, a mass of formulas and devices; masterful in knowledge of processes and in the creation of apt machinery, but ignorant of the foundations of our being and of world being; it cannot perfect our nature and therefore cannot perfect our life.'[2] Tagore echoed a similar sentiment when he observed: 'The details of reality must be studied in their differences by science, but it can never know the character of the grand unity of relationship pervading it, which can only be realized immediately by the human spirit.'[3] And Dr. Radhakrishnan wrote: 'Our boundless ability in mastering our natural environment is of infinitely less importance to us than our relations with ourselves and our fellow-men. The possession of reason is not a guarantee of our humanity. To become truly human, we need a something more than reason.'[4] This does not mean that such views are altogether absent from the work of Western writers; the

1. Presidential address of Dr. D. M. Bose to the fortieth session of the Indian Science Congress, Lucknow, 2 January 1953.
2. Sri Aurobindo, *The Life Divine*, New York, The Greystone Press, 1949, p. 917.
3. Rabindranath Tagore, *The Religion of Man*, 3rd impression, London, Allen & Unwin, 1949, p. 102.
4. *East and West: Some Reflections*, London, Allen & Unwin, 1955, p. 119.

point worth noting, however is that the glorification of the concept of intuition is a central tradition in Indian philosophy.

The tradition of attributing every work of authorship to divine inspiration (which incidentally gave rise to the cult of anonymity) hampered the progress of science in ancient India. Certain of the achievements in scientific thinking and technology of that period were truly remarkable, for example the Iron Pillar in Delhi, over 1,500 years old and one of ancient India's proudest technological achievements, and the discovery by the astronomer Aryabhatta of the theory of the earth revolving round the sun. But with the passage of time tradition curbed initiative and discouraged critical thinking. Thus we find that, in spite of some brilliant scientific achievements, science in ancient India could not develop beyond a certain point. What Zimmer says of Indian medicine is perhaps true of Indian science as a whole: 'There was no systematic experimental research, continuously yielding new facts whereby to check the speculative flight of unfounded theorizing and empty generalization. There were no closely related sciences more advanced in methods and results to dispel the mist of imaginary ideas which, covering up the objective facts found by intuition and experience, posed as a true interpretation of these facts.' Sir P. C. Ray is even more pointed in his criticism: 'The caste system was established *de novo* in a more rigid form. The drift of Manu and of the later Puranas is in the direction of glorifying the priestly class, which set up most arrogant and outrageous pretensions. According to Susruta, the dissection of dead bodies is a *sine qua non* to the student of surgery, and this high authority lays particular stress on knowledge gained from experiments and observations. But Manu would have none of it. The very touch of a corpse, according to Manu, is enough to bring contamination to the sacred person of a Brahmin. Thus we find that shortly after the time of Vagbhatta, the handling of a lancet was discouraged and anatomy and surgery fell into disuse and became to all intents and purposes lost sciences to the Hindus.'[1]

The renaissance of science in modern India derived its inspiration from the tradition of modern science as it originated is the minds of Vesalius, Galileo, Boyle, Harvey, Newton and others. This was because modern India did not inherit what may be called a true scientific tradition, although Indians may be justifiably proud of some of ancient India's contributions to science, and since the beginning of this century modern India has begun to make rapid strides in scientific activity. In his inaugural address to the Silver Jubilee Session of the Indian Science Congress, Sir James Jeans said: 'These 25 years have not only seen your association increase from infinitesimal beginnings to its present international importance; they have also seen the phenomenal growth of India as a scientific nation. In 1911

1. *History of Chemistry in Ancient and Mediaeval India*, Calcutta, 1956, p. 240.

there were no Indian-born Fellows of the Royal Society; today there are four.'[1] A number of Indians have been elected Fellows of the Royal Society, for their notable contributions to different branches of science: S. Ramunujan for his contribution to mathematics; J. C. Bose for his researches into physiology; Neghnad Saha for his pioneer work in astrophysics; Sir C. V. Raman for his discovery of the Raman effect and his investigations in sound and the theory of music; Birbal Sahni for his important work in palaeobotany, and he is also known for his interesting work on the age of the Salt Ranges in the Punjab; K. S. Krishnan for his work, in collaboration with C. V. Raman, on the molecular scattering of light and also for his investigations on magnetic methods as a supplement to methods of X-ray analysis in detecting the architecture of crystals; Dr. S. S. Bhatnager for his work in magnetochemistry; Dr. Bhabha for his valuable work in cosmic physics; Professor S. Chandrasekhar for his celebrated work in astrophysics; P. C. Mahalanobis for his contribution to statistics; Dr. D. N. Wadia for his work in geology; Professor S. N. Bose for his fundamental work in theoretical physics; and Dr. S. K. Mitra for his work in radio research.

Professor Whitehead wrote in his *Science and the Modern World* that, 'Modern science was born in Europe, but its home is the whole world.... More and more it is becoming evident that what the West can most readily give to the East is its science and its scientific outlook. This is transferable from country to country and from race to race wherever there is a rational society.'[2] Today, science in modern India is not only linked with the Western heritage of modern science, but is also a part of the Western tradition of intellectual freedom. Indeed, if we wish to preserve the spirit of scientific inquiry in India, science cannot be divorced from its tradition of intellectual freedom. Modern science, as Professor Whitehead says, is transferable from place to place; but the 'transfer' is not an easy process. Professor Michael Polanyi has some interesting observations to make on this subject: 'Modern science is a local tradition and is not easily transmitted from one place to another. Countries such as Australia, New Zealand, South Africa, Argentina, Brazil, Egypt, Mexico have built great modern cities with spacious universities, but they have rarely succeeded in founding important schools of research. The current scientific production of these countries before the war was still less than the single contributions of either Denmark, Sweden or Holland. Those who have visited parts of the world where scientific life is just beginning know of the back-breaking struggle that the lack of scientific tradition imposes on the pioneers. Here research work stagnates for lack of stimulus, there it runs wild in the absence of any proper directive influence. Unsound reputations grow like mushrooms: based on nothing but commonplace achievements, or even on mere re-

1. *Proceedings of the Twenty-fifth Indian Science Congress*, Calcutta, 1938, p. 4.
2. A. N. Whitehead, *Science and the Modern World*, Mentor edition, p. 3.

search. However rich the fund of local genius may be, such environment will fail to bring it to fruition. In the early phase in question, New Zealand loses its Rutherford, Australia its Alexander and its Bragg and such losses retard further the growth of science in a new country.'[1] In India, Ramanujan's genius could not develop fully; it was Cambridge which afforded the maximum scope for its development. Just as Rutherford, Bragg and others preferred to work in England, the eminent Indian-born astrophysicist works in the United States. From the over-all point of view, however, the 'transmission' of science in modern India has been successful, thanks to the dedicated work of men like Raman, Bose and Ray.

The 'transmission' of science in modern India has been successful until now; but the difficulty will arise in the future. Both science and the spirit of nationalism have been Western imports, but there is a tendency of late to discard Western ideals. One school of thought rejects the spirit of modern Western civilization while taking over its technology and its material results, and the other school wishes to 'preserve' traditional values, so that they may not be 'lost' in the impact of technology on Indian society. In a recent seminar,[2] a writer has argued that the values connected with science 'militate against the values of traditional culture' and that 'science and technology should duly be integrated into the essential outlook of traditional cultures and not just allowed to invade it, overwhelm and disrupt it'. On the contrary, there is a real danger of such ideals as democracy and intellectual freedom transmitted under British rule being overwhelmed by the currents of traditional culture. The point to be grasped is that no one is opposed to cultural values as such, indeed, there is no room for a conflict. The actual danger stems from the traditional outlok which is fanatically opposed to science. It is this traditional outlook, which becomes ossified into an anti-scientific prejudice. Such an attitude is not desirable when we live in a highly developed society which has passed through the era of the Industrial Revolution, the development of modern science and technology and the growth of parliamentary democracy in large areas of the world.

'The time has arrived', wrote C. E. Trevelyan in his *The Education of the People of India,* 'when the ancient debt of civilization which Europe owes to Asia is about to be repaid, and the sciences cradled in the East and brought to maturity in the West are now by a final effort to overspread the world.' Raja Ram Mohan Roy, who was inspired by the liberal ideas of the French and American revolutions, visualized the dawn of a liberal age in Indian history—science, democracy and liberty constituting the three forces of liberation as he viewed it. Seen in historical perspective, the scientific renaissance in modern India is part of India's cultural renaissance which

---

1. M. Polanyi, *The Logic of Liberty*, London, 1951, p. 56.
2. *Traditional Cultures in South-East Asia*, published under the auspices of Unesco, 1958, Orient Longmans, pp. 50, 52.

is a product of modern India's encounter with modern Western civilization. It is to be hoped that more and more of our people will realize the meaning of intellectual freedom. There can be no doubt, whatever, that traditionalism will retard the future scientific progress of the country. The 'transfer' of modern science to India is not to be viewed as a Western imposition. Modern science is not merely Western; it is universal. We may conclude with Lord Rutherford's inspiring words to the Silver Jubilee Session of the Indian Science Congress: 'May we not hope that this natural aptitude for experimental and abstract science shown so long ago is still characteristic of the Indian peoples, and that in the days to come India will again become a stronghold of science, not only as a form of intellectual activity but as a means of furthering the progress of her peoples.'

Problems of Waste Disposal in the Wide-scale Use of Radio-isotopes

by

W. G. MARLEY, M.Sc., Ph.D.

W. G. Marley is Head of the Division of Health Physics, Atomic Energy Research Establishment, Harwell. His article is based on an Evening Lecture given before the International Conference on Radio-isotopes in Scientific Research, Paris, September 1957.

The standard of public health and the well-being of populations from the health viewpoint is critically dependent upon the standard of living and the resources of the community and these in turn will profit greatly from the widespread development of the use of radio-active isotopes in improving our knowledge and our technology. The resulting benefits to public health are distinct from those which might arise directly from the use of radio-active isotopes in public health research and they may be even more significant. It is therefore important that the use of radio-active materials, as well as the development of atomic energy, should be pushed forward with the maximum expedition. The considerations to which I have to draw attention in regard to the control of radio-active waste materials are therefore formulated with a view to facilitating the expanded use of radio-active materials, to the benefit and well-being of mankind.

It is now generally recognized that the exposure of living tissue to ionising radiations can only be deleterious, and the extension of the use of radio-isotopes therefore presents the problem of minimizing the human exposures which must necessarily result. The control of occupational exposure has been considered in the associated paper by Dr. L. S. Taylor,[1] here we are concerned with the radio-active waste problems, especially in relation to public health.

THE NATURAL BACKGROUND OF RADIO-ACTIVITY

Populations have been exposed all down the ages to the natural radio-activity background arising from cosmic radiation, gamma radiation from the earth's crust and building materials, radiation from natural potassium and radium in the body, and from the radio-active gases in the atmosphere. A representative level of exposure from this cause is about 100 millirem

1. *Impact*, 1957, Vol. VIII, No. 4, pp. 230-44.

per year in most of the inhabited regions of the world. The way in which this dose is in general made up is shown in Table 1. As far as the level of irradiation from sources such as cosmic rays and radio-active elements that are constituents of the body (potassium and carbon) is concerned, the doses are representative for the whole population of the world. In the case of other sources of external and internal irradiation present in the soil, water and air, the level of irradiation depends on the geological features of the region concerned and therefore varies considerably from one place to another. Considering the external radiation, which in the table amounts to 75 millirem per year from cosmic rays and gamma rays out of doors, this figure may rise to about 190 millirem per year in granitic regions in France, 315 millirem per year in monazite regions in Brazil, and 830 millirem per year in the monazite region in Kerala in India:[1] the numbers of persons exposed in the latter two regions is, however, relatively small. The material of which houses are constructed also affects the external radiation level. In some towns in the United Kingdom the level is 15 per cent higher,[2] whilst in Stockholm it is understood to range up to 70 per cent higher. No statistically significant differences have been observed so far in the incidence of those diseases or conditions known to arise from acute radiation exposure, although some limited statistics are available from areas with rather small differences in background.[3] Consideration is being given to large-scale investigation in one of the very high radiation areas of the world.

TABLE 1. Doses of external and internal irradiation from natural sources of radiation[1]

Irradiation	*Dose mrem/year*	
	To gonads and other soft tissues[2]	*To bone*
External irradiation:		
Cosmic rays (at sea level)	28	28
Gamma rays out-of-doors	47	47
Internal irradiation:		
K-40	19	11
C-14	1.6	1.6
Ra-226	?	38
Total irradiation from all sources	95.6	125.6

1. 'Recommendations of the International Commission on Radiological Protection', *Brit. J. Radiol.*, Suppl. 6, 1955.
2. Including bone marrow since the contribution from Ra in bone does not exceed about 0.5 mrem per year.

1. *Report of the United Nations Scientific Committee on the Effects of Atomic Radiation*, New York, 1958, Annex B, p. 49.
2. Medical Research Council report, *The Hazards to Man from Nuclear and Allied Radiations*, London, HMSO, 1956, Cmd. 9780, p. 113.
3. W F. Libby, address to spring meeting, American Physical Society, Washington D.C., 26 April 1957.

PERMISSIBLE LEVELS OF EXPOSURE TO IONIZING RADIATIONS

Experience gained over the last sixty years from the exposure of human beings to X-rays and ingested radium, from the occupational hazards of medical radiologists and miners of radio-active ores and from the studies of victims of atomic bomb explosions has provided an extensive radio-biological basis for fixing acceptable levels for occupational exposure of human beings to ionizing radiation. From this experience and the data obtained from the vast amount of animal experimentation, the International Commission on Radiological Protection[1] has formulated recommended maximum permissible levels for occupational exposure, and these are now internationally accepted. In the years 1956 to 1958 the commission extended further its recommendations and designated limits for the cumulative dose as a function of age. At the time of writing only the general recommendations have been published[2] and further sections of the recommendations dealing with internally assimilated isotopes are expected to be published very shortly. The permissible levels recommended by the commission are not expected to cause any deleterious or objectionable effects on the health and well-being of the individual at any time during his lifetime. Examples of the levels recommended by the International Commission on Radiological Protection (ICRP) (1955 publication) for radio-active isotopes within the human body are shown in Table 2.

TABLE 2. Typical maximum permissible levels for occupational exposure[1]

Isotope	*Level in body* μc.	*Critical organ*	*Level in air* μc./cc.	*Level in water* μc./cc.
Ra-226	0.1	Bone	8×10^{-12}	4×10^{-8}
Pu-239	0.04	Bone, gut	2×10^{-12}	3×10^{-6}
Sr-90	1	Bone	2×10^{10}	8×10^{-7}
Sr-89	2	Bone	2×10^{-8}	7×10^{-5}
I-131	0.6	Thyroid	6×10^{9}	6×10^{-5}
P-32	10	Bone	1×10^{-7}	2×10^{-4}
Na-24	15	Lung, body	1×10^{-6}	8×10^{-3}

1. ICRP recommendations published January 1955. The International Commission on Radiological Protection is shortly publishing revised recommendations for these permissible levels.

Apart from the first three isotopes listed in the above table and a few other alpha-active materials, the majority of isotopes have a maximum permissible level in drinking water of about 10^{-4} μc./cc. or higher. It is understood that in the new recommendations of ICRP (in the press) there

1. 'Recommendations ot the International Commission on Radiological Protection', *Brit. J. Radiol.*, Suppl. 6, 1955.
2. *Recommendations of the International Commission on Radiological Protection (adopted 9 September 1958)*, published by Pergamon Press, 1959.

are only five beta-active isotopes listed for which the maximum permissible level in drinking water is less than 10^{-4} μc./cc. only one of these is markedly less than this limit and that is the rare isotope I-129. Since the half-life of this isotope is 17 million years, it is unlikely to be present in effluents to any appreciable extent.

The figures given in Table 2 relate to occupational exposure to ionizing radiation, but persons exposed occupationally comprise only healthy adults under medical supervision. The general population, on the other hand, includes persons who are not completely healthy and numbers of infants and children who are more radio-sensitive than adults. For these reasons, the various authorities, including the International Commission on Radiological Protection and the United States National Committee on Radiation Protection[1] recommend that members of the general public should not be exposed to levels exceeding one-tenth of the occupational permissible levels. In public health problems, where a source of pollution affects only a small number of people, this may well be the appropriate factor. Where, however, substantially the whole population of a country is involved, further considerations, such as those concerning the statistical incidence of diseases such as leukaemia, which may be induced by radiation and those concerning genetic effects, become of importance.

Various authorities have now expressed their views regarding the limitation of these levels. The British Medical Research Council, for instance, have commented that it is unlikely that any authoritative recommendation would suggest a figure for permissible radiation exposure for the whole population of a country greater than a level of twice the natural background level above the background level.[2] Since the background level in the United Kingdom is about 3 roentgen in a 30-year period (one generation) the limit suggested would thus be less than 6 rem per 30 years. The United States National Academy of Sciences—National Research Council Committee on Radiation Effects has suggested a limit of 10 roentgen in 30 years.[3] The latest recommendations of the International Commission on Radiological Protection suggest a figure of 5 rem additional to the natural background and the contribution from medical exposure and suggest that the genetic exposure of the population at large from development of the nuclear energy programme (with the associated waste disposal problems) and the more extensive uses of radiation sources should, for planning purposes, be restricted to 2 rem per generation. However, there is reason to believe that this figure may be somewhat too high since the consequential induction of

1. United States National Committee on Radiation Protection, *National Bureau of Standards Handbook 59*, September 1954.
2. Medical Research Council report, *The Hazards to Man from Nuclear and Allied Radiations*, London, HMSO, 1956, Cmd. 9780, p. 78.
3. United States National Academy of Sciences—National Research Council Committee on Radiation Effects, *Report on the Biological Effects of Atomic Radiation*, 1956.

genetic defects may be unnecessarily great, even allowing for the possible reduction of genetic effects when the radiation exposure is protracted.[1] The levels quoted must be taken as indicating the order of dose above the natural background which might be acceptable in the long-term development of radiation applications.

Similar considerations may well apply to certain somatic effects and especially to the possible incidence of leukaemia. In a recent British report, Court-Brown and Doll[2] have established a relationship between radiation exposure incurred in intense isolated doses, and the incidence of leukaemia. Assuming that a linear relationship exists at the very low exposure rates, which, it is stressed, has not been proved, the induction of leukaemia by radiation would be about 10^{-6} cases per year for every man-roentgen total-body exposure in a population. A similar conclusion is reached by Lewis.[3] There would thus be close similarity on this hypothesis between the significance of radiation exposure levels in relation to possible genetic effects and to possible increases in the incidence of leukaemia.

On the basis of these considerations the exposure of whole populations would need to be governed by the following principles:

1. The irradiation of members of the general public, and indeed, of any individuals, should be kept to the lowest practicable level.
2. The exposure of individual members of the general public should not be allowed to exceed one-tenth of the corresponding maximum permissible occupational levels of exposure.
3. The gonad or whole body exposure averaged over the population from all man-made sources of ionizing radiation will need to be kept below 6 rem per head in a 30-year period; the appropriate level has still to be decided and careful consideration will be needed to decide the acceptable radiation load on the population as a whole from each application of radiation or radio-activity, assessed in relation to the benefits derived.

The above considerations make no allowance for exposure to the population arising as a result of accident or emergency. Doses of this kind must clearly be included in the average population doses, but since these latter are in many instances spread over a generation, the effect of emergency exposures is not likely to be of significance. Consideration has, however, been given in the United Kingdom to permissible levels of exposure of local populations to radio-activity escaping under accident conditions and leading to exposure of persons in the neighbourhood through contamination of food supplies, especially milk.[4]

1. W. L. Russell, L. B. Russell and E. M. Kelly, 'Radiation dose rate and mutation frequency' *Science 128*, 3338, 19 December 1958, p. 1546.
2. W. M. Court-Brown and R. Doll, *Leukaemia and Aplastic Anaemia in Patients irradiated for Ankylosing Spondilitis* 1957 (Medical Research Council special report no. 295).
3. E. B. Lewis, 'Leukaemia and ionising radiations', Science *125*, 3255, 17 May 1957.
4. Maximum permissible dietary contamination after the accidental release of radio-active material from a nuclear reactor', *Brit. Med. J.*, 11 April 1959, Vol. I, p. 967.

THE BEHAVIOUR OF RADIO-ACTIVE NUCLIDES IN HUMAN FOOD CHAINS

The concentration of radio-active isotopes in biological materials forming part of human food chains has now been extensively studied. Much of this work has related to contamination of crops and herbage, the wide-scale contamination of which is unlikely to arise as a result of the applications of radio-active isotopes; nevertheless, the information is of considerable value. The release of radio-active nuclides in the form of dust or vapour over agricultural land[1] can lead to the entry of nuclides into the human food chain, either by direct contamination of crops used for human consumption or by contamination of herbage which is grazed by dairy cattle.[2] Extensive studies have been made on the behaviour of Sr-90 in the human food chain[3] and the subsequent build-up in the human body.[4] The fission product isotope I-131 has also been extensively studied[5] and it has been found that the permissible level in air over pastureland is about 1,000 times lower than that for direct human breathing.[6] Although this isotope is used extensively in medical practice, it is unlikely as a result to be released as a vapour into the atmosphere.

Biological concentration also occurs to a significant extent in aquerous systems[7] and concentrations in plankton and water-fowl of isotopes such as P-32 have been observed to exceed 10,000 times that in the water.[8] In surveys[9] of radio-activity in fish in White Oak Lake in the Oak Ridge National Laboratory, U.S.A., it was found that all the fish assayed had selectively accumulated radio-active materials in the tissues far in excess of the amounts which occurred in the water in which they lived. The selective concentration of radio-strontium in the skeleton and other hard tissues (not normally eaten) was to the extent of 20 to 30,000 times as great as that in the water. The amounts of radio-active materials accumulated in

1. H. J. Dunster, A. S. McLean, H. Howells and W. L. Templeton, 'District surveys following the Windscale incident, October 1957', Paper 316, United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.
2. L. Fredriksson, B. Eriksson, B. Ramuson, B. Gahne, K. Edvarson and K. Low, 'Studies on soil-plant-animal interrelationships with respect to fission products', Paper 177, United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.
3. F. J. Bryant, A. C. Chamberlain, A. Morgan and G. S. Spicer. 'Radio-strontium in soil, grass, milk and bone', *Journal of Nuclear Energy*, Vol. 6, 1957, p. 22.
4. W. F. Zibby, Address to Spring Meeting, American Physical Society, Washington, D.C., 22 April 1957.
5. A. C. Chamberlain and R. C. Chadwick, 'Deposition of airborne radio-iodine vapour', *Nucleonics 11*, 8, 1953, p. 22.
6. A. C. Chamberlain, J. F. Loutit, R. P. Martin and R. S. Russell. 'The behaviour of I-131, Sr-89 in certain agricultural food chains', United Nations Conference, Geneva, Paper 393, Vol. 13, 1956, p. 360.
7. J. W. Healy, B. V. Anderson, J. K. Soldat and H. V. Clukey, 'Radiation exposure to people in the environs of a major atomic energy plant', Paper 743, United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.
8. W. C. Hanson and H. A. Kornberg, 'Activity in animals near an atomic site', United Nations Conference, Geneva, Paper P/281, Vol. 13, 1956, p. 385.
9. L. A. Krumholz, *A Summary of Findings of the Ecological Survey of White Oak Creek, Tennessee, 1950-1953* (Fish and Game Branch Report ORO-132, 1954).

the soft tissues were 40-50 times lower than those accumulated in the skeleton, the primary radio-element concentrated in the soft tissues being caesium. These studies suggest that in circumstances where large numbers of fish are caught and eaten by riverside populations, especially if the bones are eaten, the level of activity in the fish may become the limiting hazard, rather than that of the water which may be used for drinking.

However, another aspect of the build-up of activity in biological organisms is that the water is incidentally considerably cleaned up by absorption on biological organisms and mud; this is particularly important where a long stretch of slow-moving river exists between the source of effluent and water supply intakes. Advantage can be taken of this factor where the extent of the clean up has been evaluated.

Corresponding concentrations in marine plankton and fish have been observed in studies on the fate of radio-activity in sea water, and it is apparent that biological concentration factors are of predominant importance in any coastwise disposal of active wastes.

SOURCES OF RADIO-ACTIVE WASTES IN THE APPLICATION OF ISOTOPES

The principal sources of radio-active wastes which are of concern to public health and which arise from the uses of radio-active isotopes are listed below:

Hospitals. Diagnostic procedures: wastes negligible.
Therapeutic procedures: P-32, I-131, and Au-198 used in large quantities.
Teletherapy sources: no wastes except possibly in the exceptional event of a serious fire.

Industrial isotope uses. Tracer, process and research experiments: small quantities of active wastes, but possible widespread use.
Production control: usually short-lived isotopes and small effluent hazard, but may be widely used in the future: possible additional dose to population from contamination in the final product sold to the public.
Radiographic sources and static eliminator sources: no wastes: escape in the exceptional event of serious fire also negligible.
Radiation chemistry: use of large sealed sources made from f.p. wastes; normally no effluent, but potential release in accident or fire needs consideration.

Research institutes and university laboratories. Tracer experiments: small quantities of active wastes, but widespread use.
Special experimental use: wastes require special consideration.

Laboratories producing special isotopes in cyclotrons: quantities very small and isotopes valuable; wastes likely to be negligible.

The problem of radio-active wastes from the various applications of radio-active isotopes is, of course, dwarfed by the radio-active waste problem[1] arising from factories processing isotopes or manufacturing isotope appliances, and especially from certain atomic energy processes. Whilst some nuclear reactors and research facilities may well be widely distributed, it seems likely that nuclear power stations, requiring large quantities of condenser water, will be located either in the vicinity of large rivers or on the seaboard and, moreover, they are not likely to give rise to significant radio-active wastes in normal operations. The separation of the fission products from the spent fuel is normally performed in chemical separation plants remote from the reactor location. The radio-active waste problem from such plants is considerable and great care is necessary in their location if a high standard of protection against the radio-activity is to be afforded to the general public.[2] The field of atomic energy wastes is rather outside the scope of the present paper.

It is possible to sum up the various sources of isotope wastes, since they appear to fall into two distinct classes. The first includes the medical therapy centres and other comparable large users of radio-active isotopes: in this class it would also be desirable to place as a precautionary measure institutions using very large fission product sources industrially for radiation chemistry. The second class includes most other users, since the levels of radio-activity released from most other isotope applications are relatively small. However, this class includes an exceedingly large number of users; the amount of radio-activity involved at each location is relatively small, but in aggregate may well be comparable with that arising from therapy centres. Before considering the implications of this situation we shall consider the possible modes of disposal of radio-active wastes.

Release of Gaseous Wastes

Gaseous wastes from fume hoods in laboratories and isotopes handling rooms in hospitals require no special precautions provided the outlet is clear of windows.[3] The only significant problems of gaseous (and particulate) waste are from atomic energy installations[4] and in such instances the breathing hazard at a distance from an outlet may be estimated by

1. A. W. Kenny, 'The safe disposal of radio-active wastes', *Bull. World Health Organization 14*, 1007, 1956.
2. J. W. Healy, B. V. Anderson, J. K. Soldat and H. V. Clukey, op. cit.
3. H. J. Dunster, 'The protection of personnel working with radio-active materials and the disposal of contaminated waste', *Medicine Illustrated, 8*, 11, November 1954.
4. J. Z. Holland, 'Progress in applications of meteorology to peaceful uses of atomic energy', Paper 2288, United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.

Sutton's theory of atmospheric diffusion.[1] In general, gaseous wastes are essentially of local concern since they can affect only a very small fraction of the population and genetic considerations are hardly of significance.

Discharge of Liquid Wastes

The permissible level of discharge to rivers depends on the use which is made of the water. Considerable quantities of radio-activity may be safely discharged when there is no subsequent human drinking, such as in rivers carrying large quantities of trade wastes, where biological concentration and adsorption on surfaces become the dominant factors and levels of 1 μc./ml. may well be acceptable. Where the water is used subsequently for human drinking the permissible level in the water depends on the population exposed and an example of control of activity in an instance of this type is seen with discharges of activity to the River Thames in England from atomic energy installations. By grouping the radio-active isotopes according to the order of the permissible levels of ingestion a simple formula was derived which enables routine control by simple radio-chemical assays of the different classes of activity, using the following data and formula (see Table 3).

This method of control has been used for many years in the active waste

TABLE 3.

Class of activity	*Representative occupational maximum permissible level*[1] *μc./ml.*	*Toxicity ratio in drinking water*
Radium	4×10^{-8}	2 500
Other alpha activities	2.4×10^{-7}	420
Sr-89 Sr-90 mixture	2×10^{-6}	50
Other beta activities	1×10^{-4}	1

1. Based on 'Recommendations of the International Commission on Radiological Protection', *Brit. J. Radiol.*, Suppl. 6, 1955.
Permissible discharge given by 2 500 (Ra) + 420 (α) + 50 (Sr) + (β) = 260 V/S
where V is river flow in cu.m./sec. at the water supply intakes;
S is large population safety factor or the ratio of the permissible level for the population to that for occupational exposure;
(Ra) is permissible discharge of radium in curies/month (other activities similarly);
(α) is the permissible discharge in curies/month of alpha-active materials other than radium;
(Sr) is the permissible discharge in curies/month of strontium isotope;
(β) is the permissible discharge in curies/month of beta-active isotopes excluding strontium.

1. O. G. Sutton, *Q. J. Roy. Met. Soc. 73*, 257 and 426, 1947.
N. G. Stewart, H. J. Gale and R. N. Crooks, 'Atmospheric diffusion of gases discharged from the chimney of the Harwell pile (BEPO)', 1954, AERE.HP/R.1452.
J. J. Fuquay, 'Meteorological factors in the appraisal and control of acute exposures to stack effluents', Paper 1834, United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.

discharge to the River Thames from the Atomic Energy Research Establishment at Harwell.[1] In this instance the population involved is over 6 million and the value of S has accordingly been set at 100. The formula may need some revision in accordance with the more recent permissible levels recommended by ICRP.

Radio-active liquid wastes from processes involving applications of isotopes can in most instances be safely discharged through public sewerage systems. The extent to which the practice is satisfactory depends largely on the nature of the isotope and the subsequent use of the water again for human drinking. For many large sewerage systems, a level of 10^{-3} μc./ml. in the sewage waste of the *premises* will provide sufficient dilution in the town's sewage for isotopes of moderate or slight toxicity. Each situation should, however, be considered quantitatively before the discharges are accepted. Some attention also has to be paid to the possible accumulation of radio-active materials in the sewage treatment plant, and studies have been made of the behaviour of isotopes in such plants[2] and in water purification plants.[3] It is also important to ensure that unnecessary radiation exposure of workers handling isotopes is avoided by appropriate laboratory procedures;[4] for instance, in order to prevent local absorption on pipes and fittings, dilution of the activity with stable isotopes of the same substance is sometimes advantageous.

Disposal of Solid Wastes

There are four principal methods of disposing of solid wastes, namely, incineration, closed storage, open burial, and sea disposal. Incineration is especially valuable for treating animal carcasses and as a means of reduction of volume, but gives rise to active gases and ash. The discharge of the gases should be clear of windows and should be monitored periodically. Burial may be used on permanently enclosed ground at levels, depending on the rainfall, such that the local ground water is not raised locally above the m.p.l. for non-occupational exposure.[5] Radio-active solid wastes from iso-

1. R. H. Burns, 'Operational experiences with a handling and treatment system for liquid radio-active wastes', *Proc. Instn. Civ. Engrs.*, Part III, 4, 22, 1955.
2. E. H. Belcher, 'Experimental studies on the fate of radio-active materials in sewage treatment', *J. Inst. Sew. Purif.*, 1951, p. 348.
3. G. E. Eden, A. L. Downing and A. B. Wheatland, 'Observations on the removal of radio-isotopes during the treatment of domestic water supplies: I. Radio-iodin', *J. Instn. Wat. Engrs.*, 1952, p. 511.
   A. L. Downing, A. B. Wheatland, and G. E. Eden, 'Observations on the removal of radio-isotopes during the treatment of domestic water supplies: II. Radio-strontium', *J. Instn. Wat. Engrs.*, 1953, p. 555.
4. *Code of Practice for the protection of persons exposed to ionising radiations*, London, HMSO, 1957.
5. R. E. Brown, H. M. Parker and J. M. Smith, 'Disposal of liquid wastes to the ground', in: United Nations, *Peaceful Uses of Atomic Energy*, New York, 1956, Vol. 9, p. 669.
   R. E. Brown and D. W. Pearce, 'Experience in the disposal of radio-active wastes to the ground', Paper 1767, United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.

tope usage can safely be disposed of in the oceans and this subject is considered separately below.

Disposal of Radio-active Wastes to the Seas and Oceans

The disposal of radio-active wastes arising from the uses of isotopes (as distinct from certain atomic energy operations) may well be made in shallow coastal waters. The important requirement is that the disposals of solid materials should be made so that they cannot be entangled with the trawling gear of fishermen, and it is suggested that recognized dumping points be established for such disposals. Permissible discharges into coastal waters can be evaluated from the British experience extending over many years in regard to the discharges from the Windscale Atomic Energy Plant in Cumberland.[1] Studies were made of the movement of surface waters and of the breeding and migratory habits of fish of economic importance, and of the build-up of activity in biological systems and on the shore line. The results of this work show that, without any limitation on the normal commercial fisheries and without any restriction on the use of neighbouring beaches for recreation or on theuse of seaweed in specialized types of food, no hazard to the population should arise even if discharges are made at the rate of several hundred curies per day: on the contrary, the aggregate population exposure is negligible. It is quite clear that radio-active wastes from the applications of radio-active isotopes could well be disposed of in this way, with negligible exposure of the local or general population.

There is no necessity to have recourse to the deep oceans for disposal of wastes from isotope practice. Moreover, methods[2] have been worked out for the handling, separation, utilization and safe storage of the high-activity fission products from a nuclear power programme without there being any incentive to use the deep oceans for the high activity long-lived materials, and it is quite clear that such power programmes can be embarked upon without any significant public health hazard being necessarily incurred from the enormous quantities of radio-active fission products produced.

DISCUSSION ON CONTROL OF RADIO-ACTIVE WASTES

It is possible to draw some general conclusions regarding procedure in the control of radio-active wastes.

1. It is recommended that in each district in which significant quantities of

1. H. J. Dunster, 'The disposal of radio-active liquid wastes into coastal waters', Paper 297, United Nations International Conference on the Peaceful Uses of Atomic Energy, Geneva, 1958.
2. E. Glueckauf, 'Long-term aspects of fission product disposal', in: United Nations, *Peaceful Uses of Atomic Energy*, New York, 1956, Vol. 9, p. 3.

radio-active materials are utilized a careful survey should be made of the sources of drinking water both as regards large populations and local populations. It is possible at once from such a survey to evaluate the extent of the controls which are necessary. It would be necessary to define for each supply the factor S by which the occupational maximum permissible levels are to be reduced and this is likely to range from 10 for small populations to about 100 where a substantial part of the population of the country is involved. It is likely that many supplies will be derived from sources which cannot be contaminated by radio-active wastes.

2. It is recommended that a continuous record be kept of the distribution of the larger quantities of isotopes in each country. Little significance attaches to the use of quantities in the microcuries range but the distribution of millicurie quantities and particularly curie quantities (mostly to therapy centres) can be analysed to ensure that the waste from these particular locations does not contaminate to an excessive degree the drinking water supplies of local or large populations. In some instances no restrictions are necessary, since the effluent from the district is not used for public drinking water. This is the situation, for instance, at the Radiotherapy Centre at Cambridge, England, where the river below the town is not used for drinking water purposes. On the other hand, some centres are located on rivers used for public supply. In some of these instances it is still often sufficient simply to know the total quantity of radio-activity introduced into the centre, from which it can be seen at once that the river cannot be excessively contaminated.
3. As far as possible it is desirable to ensure that trade wastes carrying large quantities of radio-active materials are conducted away in trade sewers to a tidal estuary so that drinking water pollution cannot arise from this cause. This is particularly important in regard to premises where very large quantities of radio-activity (in the megacurie range) are manipulated. The problem is particularly acute in relation to chemical separation plants connected with the atomic energy industry, and great care is necessary in the location of such plants.
4. In many countries existing legislation relating to the discharge of noxious materials may not be adequate or appropriate to control properly the discharge of radio-active materials and may need revision. It is important to recognise that the public health hazards from such materials are to a large extent nation wide and legislation which involves local control is often inadequate. This is particularly the case with radio-active pollution of rivers. Legislation needs to take account of the large number of users of small quantities of isotopes so that negligible organizational and administrative work is entailed in their control without any loss in the control of large discharges.

5. A special problem exists in regard to discharge to rivers flowing through successive countries, and it is strongly recommended that formal machinery for collaboration be set up regarding the pollution of such rivers with radio-active waste materials. This is particularly important where chemical separation plants associated with atomic energy projects are located near such rivers. An extensive radiological study—involving considerable experimental discharges—on the fate of specific radio-active nuclides in such river systems may well be justified.
6. It is recommended that the public health authorities in countries utilizing radio-active isotopes should have specialists sufficiently well informed on the measurement and biological characteristics of these materials to exercise centralized control; in many instances this will involve actual measurement of samples at very low levels of radio-activity, for which a special laboratory and facilities are desirable.

There is no doubt that with careful planning and proper quantitative supervision of the disposal procedure the widespread use of radio-active nuclides in scientific research, in medicine, and in all branches of industrial technology can be very greatly expanded without any risk to the public health.